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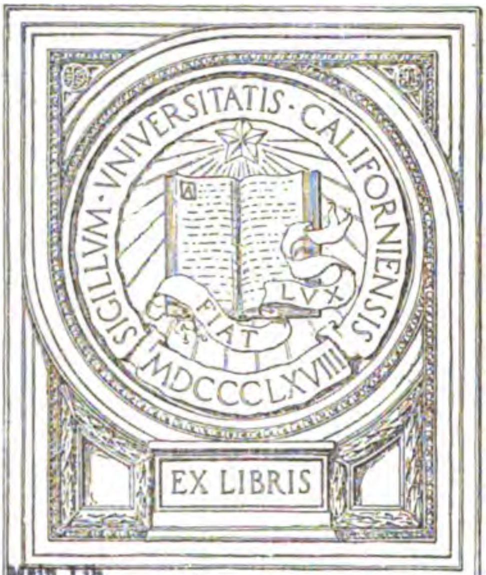

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PREPARATION AND USES OF TAR AND ITS SIMPLE CRUDE DERIVATIVES

BY

W. W. ODELL

FORESTRY

ILLINOIS COAL-MINING INVESTIGATIONS
COOPERATIVE AGREEMENT

[This report was prepared under a cooperative agreement with the Illinois State Geological Survey and the department of mining engineering of the University of Illinois]

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THE PREPARATION AND USES OF TAR AND ITS SIMPLE CRUDE DERIVATIVES.

By W. W. ODELL.

INTRODUCTION.

The importance of tar as a commercial product has been emphasized during the past five or six years more than ever before. In that time, the market for tar and its products fluctuated in an unprecedented way, because of the war and other conditions, with the result that the production of tar and tar products increased greatly. A large proportion of the increase is due to the installation of by-product coke ovens, which are fast replacing the beehive ovens, from which tar and other by-products are not recovered. The increasing demand for steel and the shortage of anthracite coal during the war were a great impetus to the coking industry. In 1920 tar was being produced in greater quantities than ever before, but the entire output was not on the market for sale, as increasingly large quantities were being used for fuel. However, in some localities where the output of tar was small or was of inferior quality—particularly water-gas tar—there seemed to be no great demand for the product.

This paper discusses the uses to which some of the various tars are put and shows briefly the usual methods of working up tar into some of its simple or easily prepared derivatives, for which a market can generally be found. Although coal tars are given chief consideration, the properties and characteristics of water-gas tar are mentioned, for the reason that this tar is often produced in plants where coal tar is made, the mixed tar being collected and marketed, and for the further reason that the presence of water-gas tar in some coal-tar products is specifically interdicted by commercial specifications. This publication is not a handbook on tar distillation, for that subject can hardly be covered adequately in such limited space, but is published by the Bureau of Mines as a general treatise on the utilization of tar.

SOURCES, VARIETIES, AND PRODUCTION OF TAR.

DEFINITION.

Different people have different ideas as to what is meant by tar; some regard it as a black, hard "chewable" substance which is shipped in open barrels and used for roofing buildings (in reality this is pitch or asphalt). Others think of it as a mysterious substance from which headache powders, colors, dyes, and other chemicals are obtained. Part of the popular misconception regarding the chief uses of coal tar may be due to such definitions of tar as are given in some dictionaries. Although only a small proportion of the tar manufactured is actually used for making drugs, chemicals, flavoring extracts, and headache powders, it is not uncommon for dictionary definitions to state that tar is a black viscous liquid from which these and similar products are obtained. According to Webster's dictionary:

> Tar is a thick, brown to black viscous liquid obtained by the destructive distillation of wood, coal, peat, and other organic materials, and having a varied composition according to the temperature and material employed in obtaining it.

From this definition one can readily see that there is a possibility of producing an almost endless variety of tars by distilling substances of a nature similar to wood, coal, and lignite at various temperatures and under different conditions. It does not follow, however, that in order to understand tars one must have a complete knowledge of the chemical differences and exact chemical nature of each one. Some tars are quite similar in many respects, in spite of the fact that they are made under different conditions and contain varying amounts of the constituents that go to make up tar.

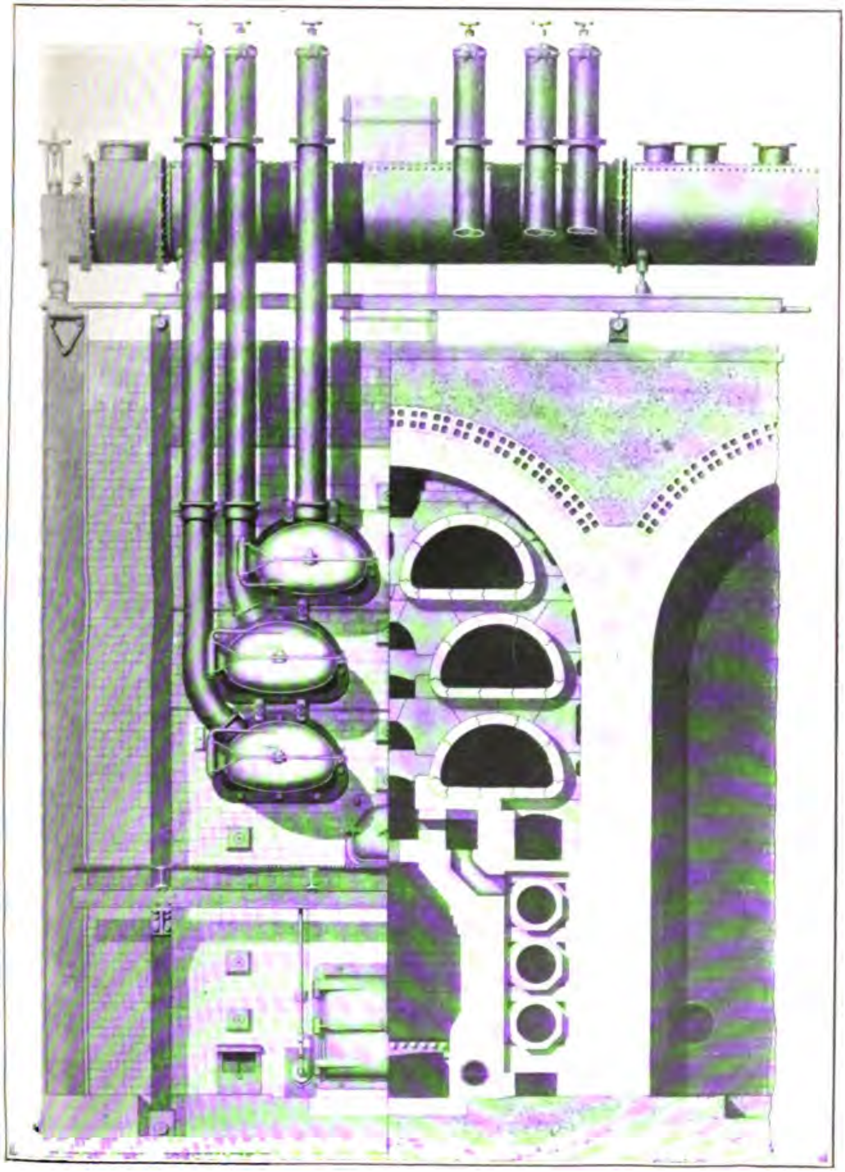
CHIEF SOURCES OF TAR.

Although it is possible to produce an endless variety of tars, the varieties commonly found on the market in appreciable quantities are few in number and may be listed under the general heading of tars produced as a by-product in the manufacture of combustible gas or coke as follows: Horizontal-retort tar, inclined and vertical retort tar, by-product coke-oven tar, water-gas tar, producer-gas tar, and oil-gas tar.

In fact, a more general classification can be made, and the chief varieties of tar on the market may be classed as: Coal tar (including retort tar and oven tar), water-gas tar, and mixtures of coal tar and water-gas tar.

COAL TAR.

According to definition, coal tar is obtained by the destructive distillation of bituminous coal, as in the manufacture of coal gas. New methods of manufacturing coal gas have been introduced in recent years, which in turn have resulted in corresponding changes in the properties of coal tar. In times gone by coal gas was manufactured by heating coal to 1,200 or 1,500° F. in horizontal clay retorts.



MODERN HORIZONTAL BENCH OF SIX RETORTS. (COURTESY OF THE IMPROVED EQUIPMENT CO.)

Later, silica retorts replaced those of clay and made possible the use of higher temperatures for carbonizing the coal in order to shorten the time of carbonization and increase the gas-making capacity of the plant. In other words, by using a higher temperature the coal could be coked and the gas obtained more quickly. Plate I shows a modern type of a horizontal-retort bench of six retorts and portrays the construction of retorts, flues, furnace, and gas offtakes or standpipes. In the past the by-products of coal were not given the serious consideration that they receive to-day, and less attention was paid to the properties of tar and to the conditions governing or affecting these properties. The advent of the vertical retort brought a further change in the properties of coal tar, as the length of time that the heavy vapors distilled from the coal are in contact with the hot chamber walls is not the same in vertical retorts as in horizontal retorts. In the vertical retorts the coal is charged periodically at the top and the coke is removed periodically at the bottom. Plate II shows a vertical section and elevation of a modern vertical retort system.

BY-PRODUCT COKE-OVEN TAR.

By-product coke-oven tar is a particular kind of coal tar. In by-product ovens coal is carbonized in greater mass and the carbonization period is longer. Although the common gas-house practice is to carbonize coal in retorts for 4 to 8 hours, the average time of carbonization in the by-product coke industry is 18 hours. In by-product ovens the coal is not heated so rapidly, but it is finally exposed to a higher temperature, resulting in the production of a greater volume of gas and a different quality of coke and tar. Plate III shows a battery of Koppers coke ovens with coke being pushed from one oven into the quenching car.

WATER-GAS TAR.

In the manufacture of carbureted water gas about half a gallon of tar is produced as a by-product for each thousand feet of gas made. Coal is not the source of this tar, however, as it is not the common practice to use coal as fuel in the manufacture of water gas, for this gas is produced by forcing steam through a body of incandescent coke rather than coal. The steam is decomposed and reacts with the carbon, with the resulting production of carbon monoxide and hydrogen. The gas usually produced is not rich enough in illuminants to meet most standards for city gas and has to be enriched by carbureting, that is, by spraying oil into the gas in chambers containing red-hot checker bricks. The high temperature volatilizes the oil, and fixes it as a gas. Some heavy vapors formed in oil carbureting are not permanent gases but condense out of the gas on cooling. The liquid so condensed is known as water-gas tar. Plate IV shows a complete carbureted water-gas set.

The properties and nature of water-gas tar naturally vary according to the temperature of the checker-brick chambers in which the oil is cracked or gasified, the rate at which oil is admitted to these chambers, the kind of oil used, the size of the checker-brick chambers, and other variables.

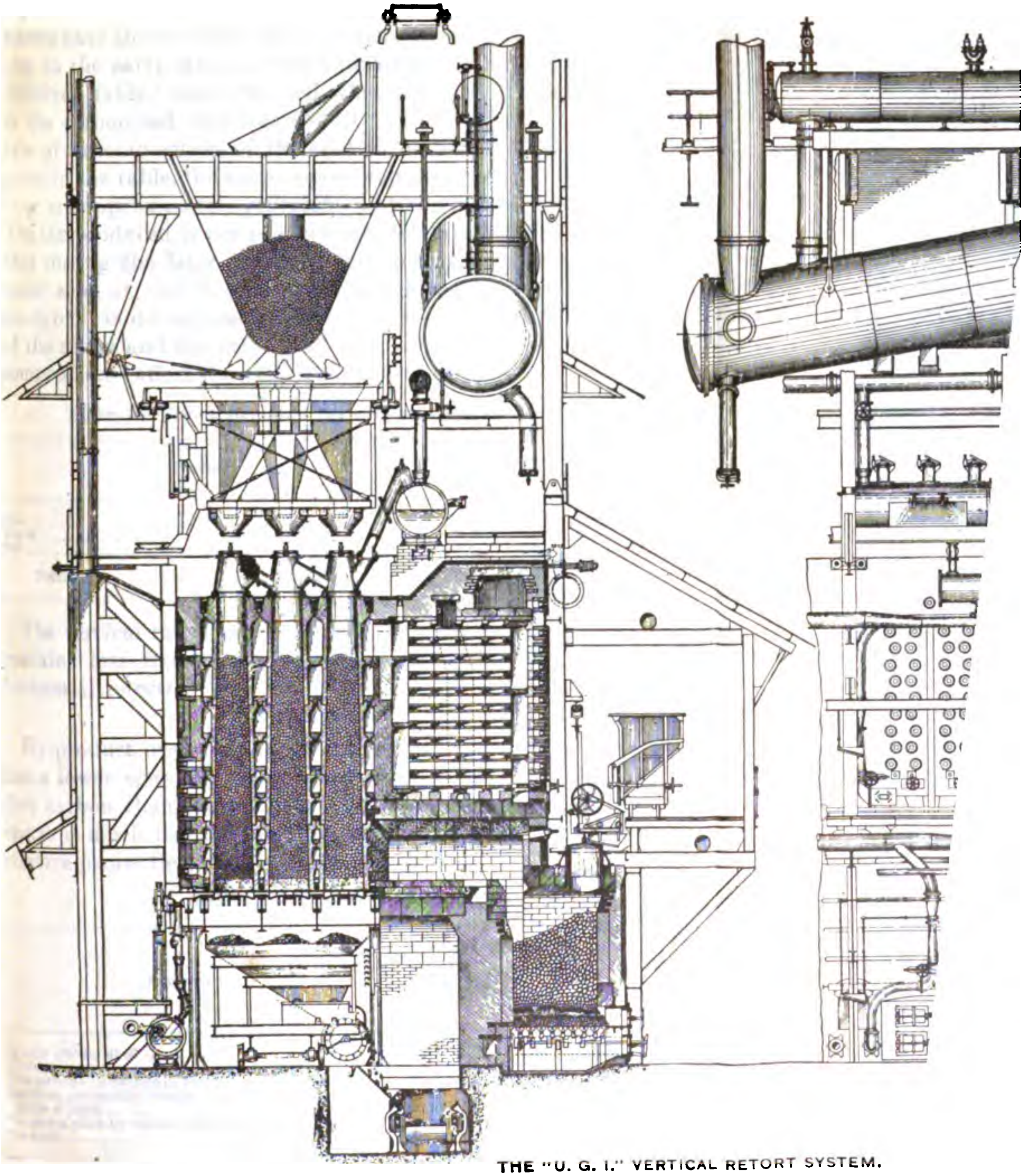
PROPERTIES OF TARS.

COAL TAR.

RETORT-GAS TAR.

Retort-gas tar, which is obtained as a condensation product in hydraulic mains, scrubbers, and condensers in the manufacture of illuminating gas by the carbonization of bituminous coal in retorts, is a black viscous liquid that contains less of the lighter hydrocarbons and more anthracene, naphthalene, heavy hydrocarbons, and free carbon than the tars from some other sources. The specific gravity (weight per unit of volume compared with weight of an equal volume of water) of water-free retort-gas tar ranges from 1.10 to 1.25, according to operating conditions in the plant and the kind of coal used. Usually a tar of the higher specific gravity is more viscous and less free-flowing than tar of the lower specific gravities. The so-called " free-carbon " content varies considerably. Tar from horizontal retorts usually contains 18 to 30 per cent of free carbon, whereas vertical-retort tar usually contains less than 5 per cent, and much of it as low as 0.4 of 1 per cent. Tar from inclined retorts does not differ widely in this respect from the product of horizontal retorts, the free carbon content being 12 to 20 per cent. Although it may be said, in general, that these tars have much the same constituents, but in varying proportions, it is to be noted that the horizontal-retort tar with a high specific gravity and high free-carbon content yields an appreciably greater percentage of pitch or hydrocarbons having a high boiling point. Tar obtained by carbonizing coal at low temperatures differs considerably from ordinary retort tar in both chemical and physical properties, and is in some respects much like a mineral oil, although its acid content is very high. So far as the author knows, this kind of tar is not being produced commercially in large quantities, and is mentioned here merely to point out the effect of the temperature of carbonizing on the resulting tar.

Differences between the various tars are in great measure due to the rate, duration, and completeness of heating of the coal, the amount of exposure of the tarry vapors to hot brick or coke surfaces, the temperature of these walls, and the exposure of the vapor to the final temperatures reached in the coking chamber. All of these par-



THE "U. G. I." VERTICAL RETORT SYSTEM.

Courtesy of the United Gas Improvement Co.

ticulars are considered in the design of chambers or retorts for coking coal. Euchene's experiments in carbonizing coal in horizontal retorts have shown that a large proportion of the tar produced comes over in the early stages of carbonization. His results, given in the following table,[1] were obtained when the final average temperature in the carbonized fuel was 950° C. (1,742° F.). Considering the rate of decomposition of the coal to be proportional to the totals given in the table, the amounts decomposed from the first to the last hour are approximately represented by the figures 40, 30, 20, and 11. The tar produced is not proportional to these figures, for the reason that during the later stages of carbonizing, the tar formed in the inner zone of coal has to pass through a zone of hot coke, where much of it is decomposed. Thus one can see that the size and shape of the retort and the manner of removing the gas—which affect decomposition—affect the yield and quality of tar.

TABLE 1.—*Tar, water, and gas produced during carbonization.*

Products.	First hour.	Second hour.	Third hour.	Fourth hour.	Total.
Gas	17.3	16.6	14.3	9.5	57.7
Water	12.3	7.3	2.9	1.0	23.5
Tar	10.1	5.3	2.8	.6	18.8
Total	39.7	29.2	20.0	11.1	100.0

The vertical retort tar is thinner, has a lower specific gravity, and contains less free carbon and more tar acids than the tar from horizontal retorts.

BY-PRODUCT OVEN TAR.

By-product oven tar is less viscous; is lighter in weight—that is, has a lower specific gravity; contains more oils, less pitch, and less free carbon than the tar from horizontal retorts; and in some respects is much like the tar from vertical retorts. Table 2 shows the relative properties of the various coal tars:

TABLE 2.—*Properties of coal tars.*

Properties.	Gas-works coal tars.			Coke-oven tars.
	Horizontal retorts.	Inclined retorts.	Vertical retorts.	
Specific gravity at 60° F	1.20 to 1.25	1.10 to 1.20	1.10 to 1.15	1.17 to 1.22
Viscosity	High.	Medium.	Low.	Low.
Free carbon [a] (insoluble in benzol) per cent	18 to 30	10 to 20	0.4 to 5	2 to 12
Distillate, per cent by volume, on distilling to a medium grade of pitch	20 to 30	25 to 35	30 to 40	25 to 35
Per cent of pitch by volume (medium pitch), plus losses.	70 to 80	65 to 75	60 to 70	65 to 75
Tar acids per cent	1.6 to 3	3 to 5	7 to 8	0.4 to 2.5

[a] The so-called free carbon, which is a constituent in varying quantities of all tars, is not pure carbon, as the term might lead one to think, but consists of complex relatively insoluble carbon compounds containing approximately 94 to 95 per cent of carbon.

---

[1] Wagner, F. H., Coal and coke. New York. 1916, p. 293.

WATER-GAS TAR.

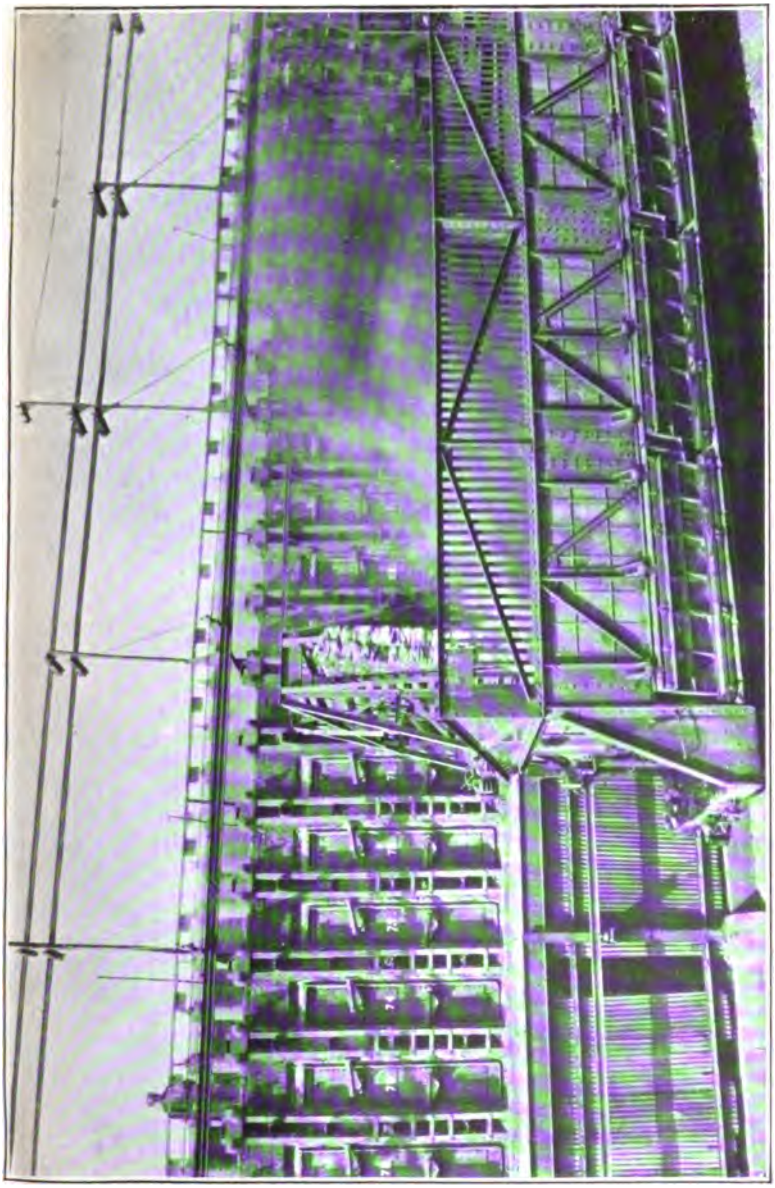
Water-gas tar has an entirely different origin from coal tar and, in addition, differs from coal tar both physically and chemically. In appearance, however, it is much the same, except that it is much more fluid; that is, it has the consistency of water or oil. When a small quantity is rubbed between finger and thumb in a thin layer, it appears to be brown to black. Its specific gravity is very nearly the same as that of water, but when free from water, the specific gravity may be as high as 1.15. Water-gas tar from small gas plants where the gas is produced intermittently varies more, both in composition and in physical properties, than in the larger plants where operation is continuous. Tars with specific gravities little greater than that of water (1.00) are not separated from water as readily as the heavier tars. Frequently, water-gas tars are found that carry considerably more than 50 per cent of water. Such a fluid is, to be specific, an emulsion of tar and water, yet in appearance it is tar. Water-gas tar contains compounds known as paraffins which are not present in coal tar. It is further distinguished from the latter by its not containing any appreciable amount of tar acids. Free carbon is seldom present in amounts greater than 1 to 4 per cent.

RAW AND REFINED TARS.

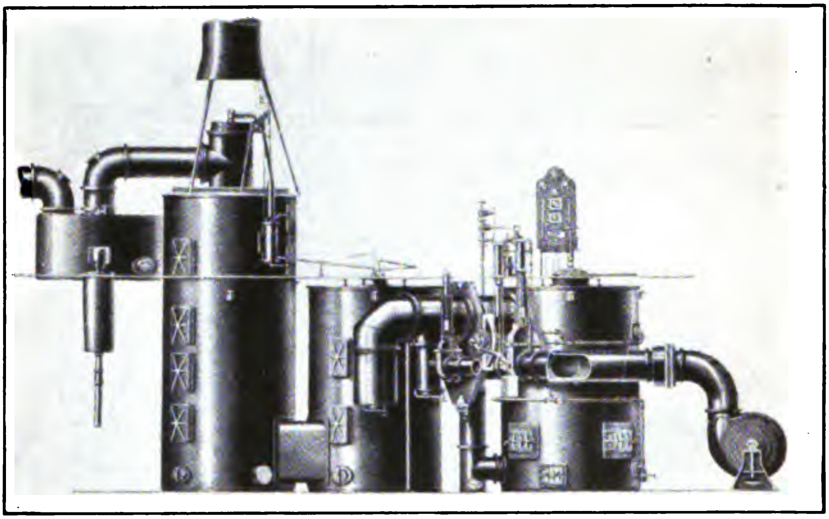
Raw tar is tar as collected at the works; it contains water in various proportions and frequently small amounts of ammoniacal liquor. For most purposes it is desirable that the tar be freed from both of these ingredients, hence it is usually sold to consumers in other than the raw state.

Refined tar has had these ingredients removed by the application of heat. In some plants the tar is heated in vertical tanks by a coil immersed near the bottom; then it is drawn off from the bottom and sold as refined tar. The tar thus treated is not free from water or ammonia but is, perhaps, more suitable for most purposes than the untreated tar. When tar is heated in a closed tank until the water, ammonia, and crude naptha or " first runnings " are removed, the remaining tar might more properly be termed "refined tar." For certain uses it is desirable to continue the heating a little longer, volatilizing and removing more of the lighter oil constituents of the tar; the resulting heavy tar is also called refined tar. When it is purchased in quantities and when the particular use to which it is going to be put is known, the tar is usually refined to suit a given specification.

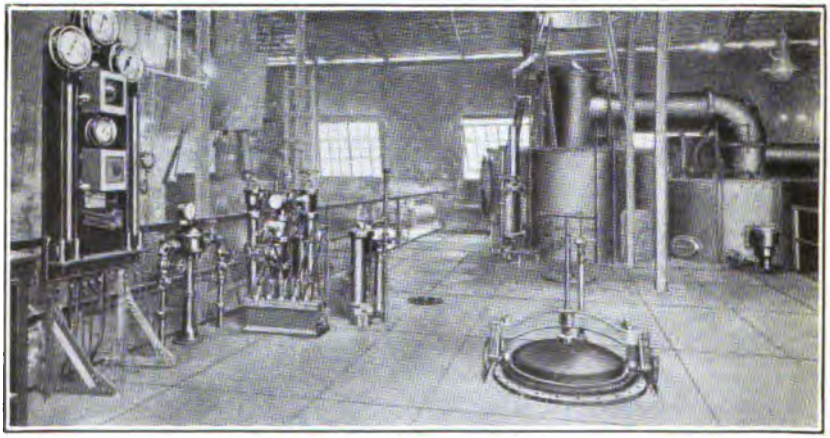
Boiled tar is a name often given to tar that has been refined. The custom prevailed at one time of boiling tar in open vessels



BATTERY OF KOPPERS COKE OVENS, SHOWING DISCHARGE OF HOT COKE INTO CARS. (COURTESY OF THE KOPPERS CO.)



A. COMMON TYPE OF WATER-GAS SET IN USE AT PRESENT.



B. OPERATING FLOOR WITH CONTROL VALVES AND GAGE FOR ABOVE SET.

(usually in small quantities of less than 1,000 gallons) with constant stirring, the heating being stopped when the tar had the consistency desired for any particular purpose. The wastefulness of this practice and the danger from fire, and the small quantity that could be treated at a time have led to the adoption of more suitable means of refining.

Tars that have been refined are heavier and more viscous than raw tar, their viscosity depending on the degree of refining. When refined only to the point where the water is completely expelled, the tars have the relative viscosities given in Table 2. When refining is continued until a large proportion of the oil constituents of the tar have been vaporized and removed, the resultant product is no longer called refined tar but distilled tar, or pitch.

TAR DISTILLATION.

According to Webster's dictionary, distillation is "the operation of driving off gas or vapor from liquids or solids, as by heat, in a retort or still, and condensing all or some of the products in a cool receiver or condenser." It follows tar distillation means the application of heat to tar contained in a still, whereby vapors are driven off and condensed by coming in contact with cool surfaces or condensers.

METHODS.

The simplest way to distill tar would seem to be by means of a direct fire placed beneath a closed tank having a take-off for the vapors and a means of cooling and condensing them. A pipe connected to the top of the still, large enough to carry off the vapors as they are formed, is a simple equipment for removing them. When a part of this pipe is cooled, as by immersion in cold water or by a water spray, the vapors condense to a liquid and the part of the pipe being cooled is called the condenser.

Essentially this method is commonly employed for distilling tar at present. Improvements are frequently made in furnace design for efficient heating of the still, and numerous changes in stills have been suggested from time to time. Various methods have been devised for cooling the distilled vapors, some of which utilize the heat given up on condensing to preheat the tar to be distilled. Other improvements have been made in the process during its evolution, but the fundamental principles are generally utilized in a very simple way.

When heat is applied to tar contained in a still, the first change that takes place is the volatilization of the very light oils and the water contained in the tar. These vapors pass out through the offtake and are cooled in some suitable and convenient manner. On condensing to a liquid, the light oil and water can easily be separated. As more heat is applied, heavier vapors (the vapors of oils having a higher boiling point) distill off. The application of heat can be continued until finally the volatile oils have all been evaporated and only carbon or coke is left in the still. The oils that distill off from the tar in this manner increase in density (specific gravity) from the beginning to the end of distillation. The character of the residue in the still depends on the extent of distillation; that is, if it is carried to completion, the residue is coke; if the distillation is stopped before all the heavier fractions are vaporized and driven off, the residue is pitch. The more oil left in the residue, the softer is the pitch, and vice versa.

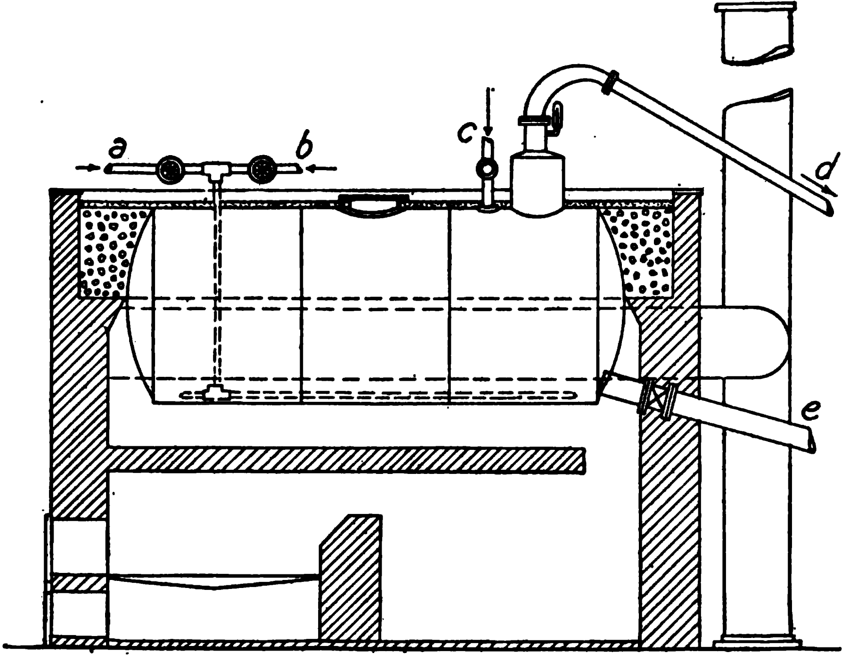


FIGURE 1.—Tar still, common boiler type: *a*, Steam inlet; *b*, air inlet; *c*, tar inlet; *d*, vapor offtake leading to condenser; *e*, pitch offtake leading to cooler.

Distillation may be carried on in various ways. One of the most common types of stills used for this purpose in the United States is a cylindrical horizontal steel shell set in brickwork to protect it from direct contact with the flames, as shown in figure 1. Provisions are made for admitting the tar, removing the vapors, and withdrawing the residue or pitch. A safety valve prevents explosions if the offtake or condenser coils become choked. Air and steam jets are also shown in the figure and are used to finish the distillation after the lighter fractions have distilled off.

In Europe, the vertical still is said to be more generally used. This type, shown in figure 2, consists of a vertical shell of about the same diameter as height, with a concave bottom, set similarly over a brickwork furnace, and having an arch protecting the bottom from the direct action of the fire. The vertical still requires less fuel, and time to distill a definite amount of tar, chiefly because of the increased heating surface exposed to the hot gases from the furnace. In the horizontal type, slightly less than half of the cylindrical surface of the still is heated.

Another still, regarded with favor by some of the companies operating large plants, is a modification of the horizontal boiler type. Large flues pass through the tar lengthwise and the waste-furnace gas—burned gas—passes through these flues before it enters the stack. The superiority of this still is due chiefly, but not entirely, to the increased heating surface—increased for a given size shell—provided by the flues.

Processes, some of which are in use, have been developed for the continuous distillation of tar. The Hird and Wilton systems[2] are said to be very satisfactory. Hird's process utilizes four stills at once, but only a part of the distillation is done in any particular still. The lighter fractions are removed from still 1, the next heavier fractions from still 2, and the final fractions and the remaining pitch from still 4. An arrangement of baffles compels the tar in going through a still to pass in a circuitous manner from inlet to outlet. Before entering still 1 the tar is heated by the sensible heat of the pitch; that is, the tar passes through pipes within the pitch coolers before entering that still. In the Kubierschky system,[3] another continuous process that has attracted some attention, the tar is blown into the still in a spray. Superheated steam blown from below comes in direct contact with the tar. The distillation progresses in stages in a series of chambers.

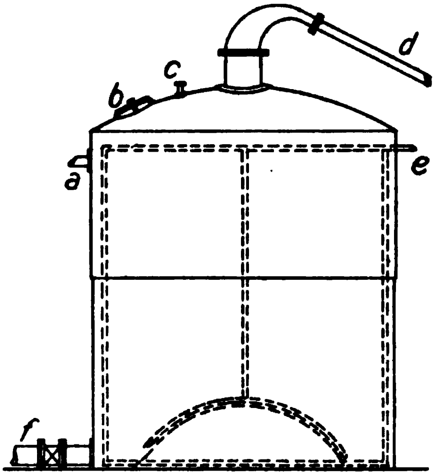


FIGURE 2.—Vertical tar still, European type: *a*, Tar inlet; *b*, man-hole; *c*, safety valve; *d*, distillate offtake; *e*, steam inlet.

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[2] Chambers, E. V., Tar dehydration: Jour. Gas Lighting, vol. 132, 1915, pp. 261–264; Livesey, Frank, Some notes on the partial distillation of tar in a Wilton's continuous still: Pp. 373–375; Wardell, R., Notes on tar dehydration: Pp. 375–377.

[3] Borrman, C. H., Tar—New methods used in washing and distilling liquids: Ztschr. angew. Chem., Jahrg. 28, 1915, pp. 377–380, 381–388; Jour. Soc. Chem. Ind., vol. 34, 1915, p. 1232.

SEPARATION OF TAR FROM WATER—DEHYDRATION.

When tar condenses from illuminating gas there is condensed simultaneously a considerable amount of water. As it is desirable for obvious reasons that the tar be as free from water as possible, a means of making this separation is usually provided at all plants producing tar.

METHODS.

The simplest method of separating water is the "settling method," in which quantities of tar are allowed to settle in undisturbed tanks; the tar, being of higher specific gravity, settles to the bottom below the water. At some plants tar is heated to facilitate the separation, heating being particularly advantageous with tars of high viscosity. This method of separation does not afford complete dehydration of the tar; in fact, coal tar so treated contains 2 to 8 per cent of water, depending on the time of settling, temperature, nature of the tar, and other factors. Water-gas tar may retain 40 per cent or more water.

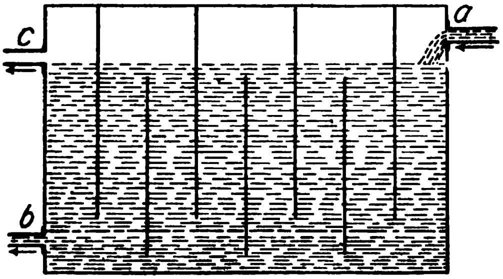

FIGURE 3.—Baffle-plate tar separator: *a*, Tar and water inlets; *b*, tar offtake; *c*, water overflow.

One kind of apparatus used for the continuous separation of tar is the baffle-plate separator, illustrated by figure 3.

The tar and water are admitted at *a* and the speed of flow is so regulated that the effluent at *c* is water free from tar and the effluent at *b* is tar with some retained water.

A method by which tar can be almost completely freed from water, although at great expense, consists in spraying the tar over heated surfaces in a vacuum. The vapors are condensed and the small amount of light oil driven off with the water is recovered. By this process, it is claimed[4] the water content in tar can be reduced to less than 0.5 per cent.

Tars with specific gravities approaching that of water can not be separated from the retained water by settling, but can be successfully freed by the centrifugal method, whereby the water content can be reduced to less than 1 per cent. The centrifuge is operated at a speed of 3,000 to 17,000 revolutions per minute. This method is best adapted for the dehydration of water-gas tar.

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[4] Perry, R. P., Tar distillation in the United States, general development and recent progress: 8th International Congress of Applied Chemistry, vol. 10, 1912, p. 242.

Centrifuging removes part of the free carbon which adheres to the wall of the separator (centrifuge) and must be periodically removed.

In the Feld system of fractional separation the dehydrated tar products are separated directly from the gas by cooling and condensing. The process provides a progressive cooling and washing of the gas, with a progressive drop in temperature whereby the heat of the gas is utilized for separating the various tar products.

OPERATION AND CONTROL.

Tar is distilled in order to obtain more useful and valuable products. In determining what fractions of distillation are to be separated or where to make the "cut," it is necessary to know the relative value of the different fractions, the market conditions, and just how much or how little can be included in a particular fraction that is made for a special purpose or to meet a given specification. Such determination is not as difficult as it may seem, for the primary fractions customarily separated are not very numerous and the specifications for many of them are not so exacting but that they leave considerable leeway for the distiller. The value of, and demand for, the several fractions vary in different parts of the country, and it is natural in separating the most valuable fractions (to meet specifications) to include in them all the distillate that the specifications will permit. Distillers have often found that some one or more of the products of distillation is not readily salable. This lack of demand has been one of the pressing causes for investigation into the various uses for tar products, and into the possibility of changing the nature of such products by chemical or other means, in order to obtain more valuable and more salable materials. That the net result of all the studies of tar and its products was a great success is shown by the large number of intermediate and finished products derived from tar that are on the market.

ONE METHOD OF DISTILLATION.

One method of distilling and separating fractions is as follows: After the still is filled from one-half to two-thirds full with warm settled tar, and all the cocks are closed, only the main offtake being open, a fire is started in the furnace beneath the still. This fire is not forced but—quite the contrary—a heavy fire is avoided at this stage. As the tar heats, water is vaporized and condenses in the condenser. With this water is a small amount of a very light (low specific gravity) oil which is usually called crude naphtha, but in some works it is termed crude benzol. The mixture of oil and water continues to come over until all the water has been distilled, the fraction containing considerably more water than oil unless the tar has been dehydrated previous to distillation. This mixture—oil and water—is referred to as "first runnings." The more water there is in the tar, the greater is the tendency of the liquid to froth and boil over and the greater the necessity of keeping the fire low and under perfect control. As the distillation of this fraction proceeds, the proportion of water in the distillate decreases and the proportion of oil increases.

After the first runnings are "over," that is, when water no longer appears in the distillate, a "change" is made and the oil coming over is run into another container reserved for "light oil." When this change is made the oil, which usually has a light lemon color and is clear, runs more smoothly from the condenser in a steady stream. The specific gravity of the oil coming over at the time the first change is made is approximately 0.965, but sometimes the change made is at 0.950 specific gravity and just before the water has all distilled over. The mean specific gravity of the first fraction, "crude naphtha," is 0.905 to 0.920 at 60° F., varying with different tars. The distillate coming over as the second or light oil fraction has a specific gravity lower than 1.00 at 60° F. In fact, the second change is not usually made until the oil coming over has a specific gravity of 1.00 at 60° F. The mean specific gravity of the light oil is between 0.960 and 1.00, these being the specific gravity limits between which the light oil is usually separated, and is not much more or less than 0.985.

An oil heavier than water is collected after the second change is made, when the oil coming over has a specific gravity equal to 1.00 at 60° F. This is called carbolic oil, as it contains most of the carbolic acid that distills over, its odor is sharper and more penetrating than that of the lighter fractions, and its color is a deep yellow or light amber. It is collected as carbolic oil until its specific gravity reaches 1.025, or sometimes 1.03, at 60° F. The specific gravity of the whole fraction is close to 1.015. Considerable solid matter usually crystallizes on cooling and standing. The solid matter, chiefly naphthalene, is yellow and rather granular and loose as it first forms, but on slow cooling or long standing the mass frequently has the appearance of brittle wax. This fraction as a whole can be pumped before it has stood too long or has become too cold; in the latter event it must first be heated, preferably with a steam coil.

As solid matter crystallizes from this fraction on cooling, the water in the condenser must be allowed to become warmer in order to avoid "plugging" or "choking." This warming is accomplished by merely decreasing the supply of feed water to the condenser.

The next or fourth fraction to come over is called "creosote," "dead oil," or "heavy oil," and is usually the last fraction separated. It is not always the last fraction, however, for sometimes an anthracene fraction, otherwise included in the creosote, is collected.

The properties of "creosote" depend largely on the completeness of the distillation. When soft pitch is desired as a residue from distillation, the volume of creosote will be smaller and there will be usually but a small amount of solid matter crystallizing from it at ordinary room temperature (60° to 70° F.). If hard pitch is made, the volume of this last fraction is greater, as the distillation is carried further, the distillate coming over during this later stage being chiefly solid at 60° F.; hence the proportion of solids in the creosote is greater when the distillation is carried to a hard pitch. The color of the first part of the creosote fraction is amber, gradually changing as distillation proceeds to a dark amber or amber red. The solid part, if collected separately, is greenish brown or olive and greasy.

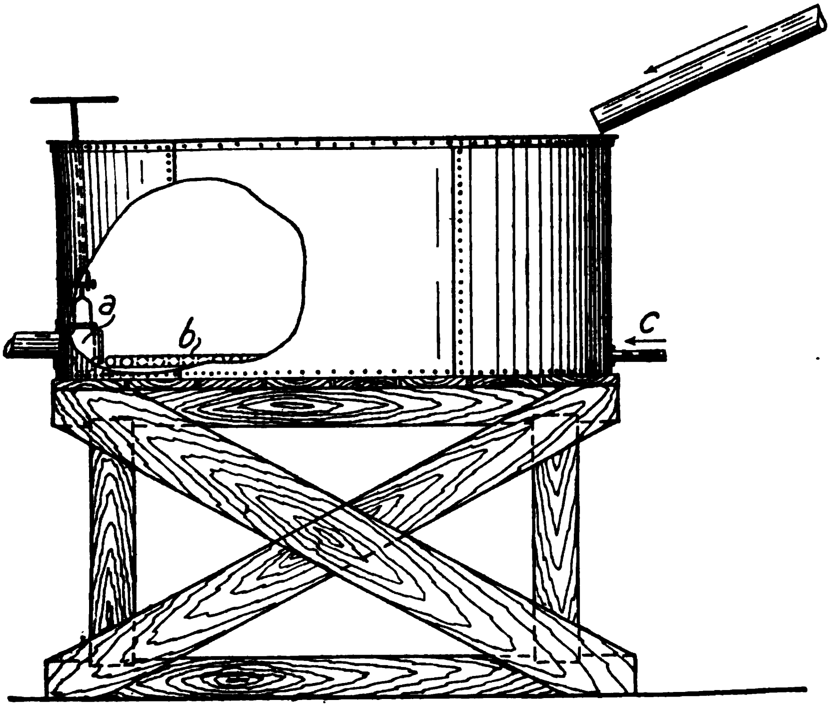

FIGURE 4.—Pitch-cooling tank used in small plants: *a*, Draw-off valve; *b*, steam coil; *c*, steam inlet to coil.

The residue in the still—pitch—is drawn off and then cooled in a cooling tank (see fig. 4) to a temperature suitable for barreling. This tank is covered to keep out rain and snow and has a steam coil for heating the pitch, in case it should become too cold before barreling. The pitch is then drawn off into tight, dry, open-headed barrels, in which it solidifies on further cooling and in which it is usually shipped. In the larger plants, however, where a very hard grade of pitch is made, the latter is generally drawn off into a specially provided pool in the open air where it is stored.

When a distillation is made to a soft or a medium pitch and the fractions separated as described the following yield may be anticipated:

Coal tar:

	Per cent by volume.
1. First runnings—	
Water	1 to 5
Crude naphtha	1 to 2
2. Light oil	1 to 4
3. Carbolic oil (middle oil)	5 to 10
4. Creosote oil (heavy oil)	10 to 22
5. Pitch	60 to 80
6. Uncondensed gases and other losses	1 to 2
Total	100

In the figures for the yield of oils just given, no deductions are made for solids that crystallize out on cooling.

The change in properties of the fractions on distillation proceeds gradually. There is no sharp mark of distinction between the oil that comes over at the end of one fraction and that which comes over at the beginning of the next. The number of fractions or "cuts" to make is determined by the distiller, who, in order to sell his products, must be guided by the demands or requirements of his customers. If the raw distillates are to be utilized in the preparation of manufactured products at the distillery, that portion of a distillate best suited for a given purpose is separated as a distinct fraction. If, for example, there is no particular use or market for carbolic oil, but there is a demand for creosote or oil heavier than carbolic, it may be possible to sell the total heavy oil collected as one fraction and thus eleminate the necessity of separating and storing a middle oil fraction. Other similar considerations arise in the operation of a tar distillery and the cuts are made in accord with prevailing conditions.

THERMOMETERS AND PYROMETERS.

When distillations or analyses are made in a chemical laboratory, the fractions are separated according to the temperature of the vapors leaving the retort or still. This is also the proper way to make cuts of a distillation in a plant still, but it is not employed in many of the smaller plants and in fact is not necessary.

Practically all stills are equipped with thermometers, which are used when tar is first distilled and when special fractions are separated. However, when only one kind of tar is used the operator soon finds that the volume, color, and smell of the distillate show him when to make a change. If the distillations are all of one given tar under approximately the same conditions, the volumes of the different fractions do not vary from one distillation to another. The chemist, distilling tar in laboratory flasks, knows between what temperature limits a given compound or class of compounds will come over. He can, therefore, define the temperature limits between which any or all the fractions will distill if he knows what the fractions are to be used for or what their specifications are. In plants where the fractions are separated in various ways and where many different tars are distilled it is essential that the operation of the still be governed by laboratory tests. Such tests will avoid many mistakes and perhaps some accidents.

It has been demonstrated by such tests and by actual works tests that some coal tars may be distilled, with the temperature as a guide, the fractions separating as follows:

1. Crude naphtha and water	[1]To 210° C.
2. Light oil	
3. Carbolic oil	210° C. to 240° C.
4. Creosote oil	240° C. to 270° C.
5. Anthracene oil	Above 270° C.

The final end point where the distillation should be stopped can not be foretold in a way that will apply exactly to all tars, the point being determined by the quality of hard or soft pitch that is desired. For a medium grade of pitch, such as is used by roofers, the firing is stopped when the odor, which is noticeably different toward the end of the "run," is more pungent and like ammonia. The heat of the brickwork will carry on the distillation, though slowly, for one-half hour to one hour. The specific gravity of the oil coming over last is usually 1.10; but when hard pitch is made, the specific gravity is 1.14. A satisfactory way of ascertaining the correct end point is to distill a small quantity of the tar in a laboratory still, observing the change in properties, odor, and color of the oil toward the end of the run, the total volume of distillate, the properties of the pitch residue, and the temperature. After an operator has made a number of distillations of a given tar he can determine the end point and end the distillations uniformly.

Another guide in determining the end for the distillation is a sample of the pitch remaining in the still. When a sample of this pitch is drawn it should be cooled as rapidly as possible to prevent excessive loss of vapors from its surface. Care should be taken to avoid the sticking of the valve through which the sample is drawn, for if a large quantity of hot pitch is let out in contact with air it is apt to take fire spontaneously.

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[1] Centigrade and Fahrenheit degrees are referred to frequently in this paper, since both are used commercially. A method converting one to the other follows:

Degrees Centigrade=5/9 (Fahrenheit temperature − 32).

Fahrenheit temperature=9/5 (Centigrade temp.) + 32.

0° C.=32° F. and 100° C.=212° F.

When hard pitch is made by mistake, it is frequently "cut back" by adding to it in the pitch tank enough of the last fraction removed by distillation to give a soft or medium pitch, as desired. When the distillation has not been carried too far, "cutting back" can be done without seriously affecting the quality of the resulting pitch, but the practice is objectionable and should be avoided when possible. If the distillation has been carried too far, "cutting back" will not remedy the error and a good quality of pitch can not be made. In fact, if the distillation is continued until the residue is a honeycombed carbonaceous mass, pitch can no longer be made from it; the residue—coke—will have to be chopped out of the still.

USE OF SUPERHEATED STEAM.

During the last stage of distillation the vapors formed in the still are very heavy and have a decided tendency to condense and fall back into the distilling tar or pitch. The more this takes place the greater is the tendency for the heavy hydrocarbons to "split up," crack, or decompose into lighter hydrocarbons and carbon. Thus the pitch may be expected to contain more free carbon than that originally present in the tar. In order to hasten this part of the distillation without increasing the temperature unduly and without forcing the fire, superheated steam is generally used in large works. By using steam the fire can be withdrawn earlier and there is not so much heat stored in the bricks at the end of the distillation; the danger of damage to the still and the tendency of hydrocarbons to "crack" and increase the carbon content of the pitch are both decreased, and the distillation can be more quickly terminated. The net result is better control of the quality of the pitch residue.

The superheated steam for this purpose is admitted to the contents of the still in small jets, which play against the bottom or the part of the wall exposed most to the action of heat. It is first blown in (for finishing the distillation) toward the end of the creosote fraction or when the temperature recorded is 270° C. Steam that is under 50 to 60 pounds of pressure and superheated to 275° C. is satisfactory. The greater the total heat of the steam, the less of it is required to distill a given amount of oil.

Both air and inert gases have been utilized to aid the distillation of tar; in addition, they have been used with steam. As use of the three at one plant is not common practice in this country it will not be discussed here. In large plants in the United States air is sometimes used with steam during the latter part of the distillation and the free-carbon content of the resulting pitch is said to be reduced 4 to 5 per cent. The volume of air used is slightly less than 30 cubic feet per gallon of tar distilled.

A vacuum method, involving evaporation under reduced pressure, has been successfully used in the distillation of tar. This is described in "Coal tar and ammonia," by George Lunge.[6] Some of the advantages of this process are:

1. Distillation can be made more rapidly.
2. Heavy vapors have practically no tendency to condense within the still and fall back into the distilling liquid.
3. The danger of clogging the offtake pipe is practically eliminated.
4. The loss of ammonia and condensable tar vapors is decreased.
5. The quality of the distillates is said to be improved.

SPECIFIC GRAVITY.

Crude tar distillates are often judged by the specific gravity test. Moreover, the different fractions formed by distillation are usually separated as the specific gravity of the oil changes. It is necessary to make use of specific gravity tests so frequently that a definition of the meaning of the term is perhaps warranted here.

Specific gravity is the ratio of the weight of any volume of one substance to the weight of an equal volume of another substance taken as standard, both substances weighed under the same conditions. As water is the standard commonly used for liquids and solids, its specific gravity is 1.0. If a container with a capacity of 2 pounds of water is filled with oil and the oil weighs 2.25 pounds, the specific gravity of the oil would be $\frac{2.25}{2.00}=1.125$. In other words, the oil is approximately 1⅛ times as heavy as water.

When the specific gravity of a substance is known, the weight of any given volume can be quickly calculated, and when the weight of a known volume is given it is a simple calculation to find its specific gravity. The weight in pounds of any known volume of a substance is roughly equal to the product of 8.33 times the volume in cubic feet times the specific gravity times 7.48. The figure 8.33 represents the approximate weight of 1 gallon of water under standard conditions, and there are 7.4805 such United States gallons in a cubic foot. These figures and calculations involving them are in frequent use by the tar distiller.

In order to avoid the necessity of weighing liquids and calculating the specific gravity therefrom, the hydrometer is universally used. This is an especially prepared float comprising a hollow glass instrument (see fig. 5, p. 23) with graduations on the narrow stem reading in terms of specific gravity or the equivalent degrees Baumé. The principle of the hydrometer is that a floating body rides higher in a heavy liquid than in a lighter one. In using this instrument, it is desirable to have the eye on a level with the surface of the liquid when the reading is taken.

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[6] Lunge, George, Coal tar and ammonia. London. 1916, vol. 1, p. 464.

Such instruments as are used in a tar distillery are generally based on the specific gravity of water being equal to 1.0 at 60° F. (15.6° C.).

Table 3 shows the relation of the different hydrometer readings for heavy liquids and for liquids lighter than water.

TABLE 3.—*Equivalent Baumé degrees and specific gravity at 60° F. (15.6° C.).*

For liquids heavier than water.		For liquids lighter than water.	
Specific gravity.	Degrees Baumé.	Specific gravity.	Degrees Baumé.
1.00	0.0	1.00	10.0
1.01	1.4	.99	11.4
1.02	2.8	.98	12.9
1.03	4.2	.97	14.3
1.04	5.6	.96	15.8
1.05	6.9	.95	17.4
1.06	8.2	.94	18.9
1.07	9.5	.93	20.5
1.08	10.7	.92	22.2
1.09	12.0	.91	23.85
1.10	13.2	.90	25.55
1.11	14.4	.89	27.3
1.12	15.5	.88	29.1
1.13	16.7	.87	30.9
1.14	17.8	.86	32.8
1.15	18.9	.85	34.7
1.16	20.0	.84	36.7
1.17	21.1	.83	38.7
1.18	22.1	.82	40.7
1.19	23.15	.81	42.8
1.20	24.20	.80	45.0
1.21	25.2	.79	47.2
1.22	26.15	.78	49.5
1.23	27.1	.77	51.8
1.24	28.1	.76	54.2
1.25	29.0	.75	56.7
1.26	29.9	.74	59.2
1.27	30.8	.73	61.8
1.28	31.7	.72	64.45
1.29	32.6	.71	67.2
1.30	33.5	.70	70.0

It is important that the temperature at which the specific gravity is taken should be noted and necessary corrections made. Occasionally, the specific gravity at 60° F. is desired of a product that is not entirely liquid at that temperature, or a determination must be made rapidly and at a higher temperature, as at the still, in which event allowance must be made for the expansion—increased volume—of the oil at the higher temperature. A similar correction must be made, in the opposite direction, when the determination is made at temperatures lower than standard (60° F. or 15.6° C.). The correction for each degree above or below this temperature is 0.0008 for each degree centigrade and 0.00044 for each degree Fahrenheit. The total correction is to be added to the observed reading when taken at temperatures higher than 15.6° C. (60° F.) and subtracted when taken at temperatures lower than 15.6° C. (60° F.). Thus, if the hydrometer reading at 85° F. (25 degrees above 60° F.) is 1.06, the true specific gravity at 60° F. is $1.06+(25\times0.00044)$ or $1.06+0.01100=1.071$. These correction factors are taken from Church,[7] and are for tar distillates only, as other oils have different factors, and although not absolutely exact, it seems to be as reliable a figure as any that can be applied to tar oils generally.

USES OF TAR AND ITS SIMPLE DERIVATIVES.

TAR.

Many uses have been found for raw or dehydrated coal tar. In fact, these are so numerous that there is no longer an excuse for throwing tar away or disposing of it wastefully. Some of the uses for tar and preparations in which it is employed are as follows: Timber preserving, fuel, tarred felt, paint for stone, brickwork, and iron, road-construction material and road-dust settler, waterproofing compounds for cement and for roof paint, germicides, and miscellaneous special preparations.

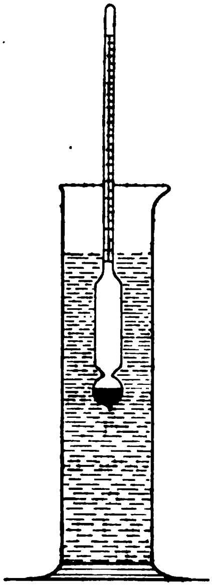

FIGURE 5.—Hydrometer method of determining specific gravity.

TIMBER PRESERVING.

For many years coal tar has been used extensively as a timber preservative; its antiseptic and preserving properties are recognized throughout the world. Tar prevents decay not only by its antiseptic properties but also by its waterproofing qualities, whereby the pores of the wood are filled. It is used to preserve fence posts, telephone poles, and heavy building timbers, and for such purposes is applied with a brush or the timbers are dipped in hot water-free tar. By far the largest proportion of the tar used for preserving timber, however, is mixed with creosote oil. Large quantities of mixtures of this nature are used annually to treat paving blocks, railroad ties, crossarms, and telephone poles. The brush method is not as common for this purpose as the closed-tank pressure method, wherein the actual absorption of the preservative is many times greater. Although it is generally understood that some of the tar distillates are superior to tar for preserving timber (especially when the proportion of free carbon in the tar is high), the difference in first cost favors tar.

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[7] Church, S. R., Methods for testing coal tar and refined tars, oils, and pitches derived therefrom: Jour. Ind. and Eng. Chem., vol. 3, 1911, p. 232.

When used for treating timber the tar should be hot and free from water, and to obtain the best results the timber treated should be as dry as possible, as the absorption and penetration is considerably greater under these conditions than when the wood is wet or moist. The penetration into the wood is not so great with tars with a high content of free carbon as with those of a low free-carbon content.

The amount of preservative required per unit of area with the brush method is greater for tar than for tar distillates. The exact amount can not be stated by a figure universally applicable, because the condition and kind of wood, as well as the quality and kind of tar, affect the results. However, it can be said that a gallon of hot tar will cover approximately 200 square feet of the surface of smooth, dry poles. More tar is absorbed by dry, rough-sawed timber, and a gallon of hot tar will cover 150 to 200 square feet of such surface.

FUEL.

Although the high heating value of tar has long been recognized, it is only in recent years that tar has been successfully utilized as fuel, partly because of a lack of understanding of the nature of the conditions under which tar can be burned satisfactorily. These conditions have been thoroughly studied[8] not only with reference to the best type of burner but to the efficiencies of operation obtainable with different burners.

The combustion space required, draft, and other factors affecting the burning of tar as fuel have likewise been investigated, and the results have had important bearing on the utilization by combustion of tar and tarlike substances.[9] The heats of combustion of coal, tar, and fuel oil, expressed in B. t. u. per pound of fuel are:

	B. t. u.
Bituminous coal as received	10,000 to 14,000
Tar (coal-gas and water-gas tar) water free	16,000 to 17,500
Fuel oil	17,000 to 20,000

Although the heating value of tar is lower per pound than that of fuel oil, it must be remembered that these substances are sold by the gallon and not by weight. The heats of combustion per gallon of the two liquid fuels are as follows:

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[8] Best, W. N., The science of burning liquid fuel: New York, 1901, 159 pp.; Peabody, E. H., Oil fuel: San Francisco, 1916, 134 pp.

[9] Kreisinger, Henry, The significance of drafts in steam-boiler practice: Bull. 21, Bureau of Mines, 1911, 64 pp.; Kreisinger, Henry, The transmission of heat into steam boilers: Bull. 18, Bureau of Mines, 1912, 180 pp.; Flagg, S. B., Cook, G. C., and Fieldner, A. C., Experiments with furnaces for hand-fired return tubular boiler: Tech. Paper 34, Bureau Mines, 1914, 32 pp.; Clement, J. K., Frazer, J. C. W., and Augustine, C. E., Factors governing the combustion of coal in boiler furnaces: Tech. Paper 63, Bureau of Mines. 1914, 46 pp.; Kreisinger, Henry, Ovitz, F. K., and Augustine, C. E., Combustion in the fuel bed of hand-fired furnaces: Tech. Paper 137, Bureau of Mines, 1916, 76 pp.; Kreisinger, Henry, Augustine, C. E., and Ovitz, F. K., Combustion of coal and design of furnaces: Bull. 135, Bureau of Mines, 1917, 140 pp.; Wadsworth, J. N., Efficiency in the use of oil fuel, a handbook for boiler plant and locomotive engineers: Bureau of Mines, 1919, 86 pp.

Tar 9½×17,000=161,500 B. t. u. per gallon.
Fuel oil 7½×19,000=142,500 B. t. u. per gallon.

If the heats of combustion of the three fuels were the only means of judging the economy in the use of one as compared with the others, the values might be expressed as follows:

Heat of combustion in $100 worth of fuel.

	B. t. u.
Coal of 12,000 B. t. u., at $4 per ton	6,000,000
Oil of 19,000 B. t. u., per pound, 7½ pounds per gallon, at 5 cents per gallon	2,850,000
Tar of 17,000 B. t. u., per pound, 9½ pounds per gallon, at 4 cents per gallon	4,037,500

However, the heating value of the fuels can not be taken as a guide for computing actual fuel costs, because the liquid fuels are burned to complete combustion with a smaller excess of air than is possible with bituminous coal. This fact allows a greater saving to be made than is apparent by comparing the relative heating values.

ADVANTAGES OF TAR FUEL.

Further advantages of using tar fuel are given below:

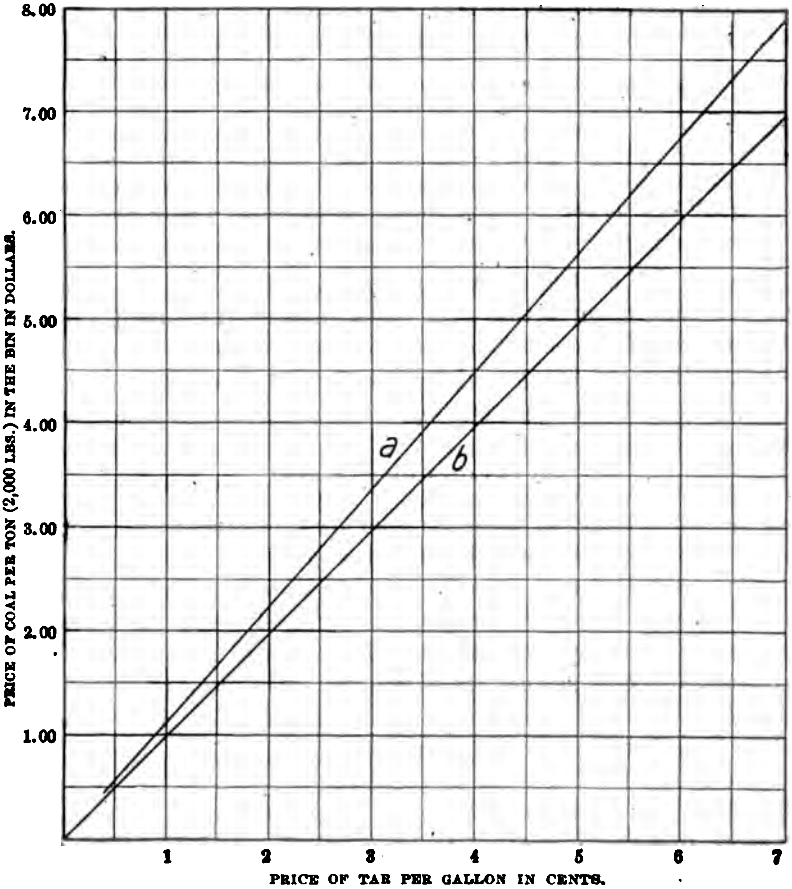
There are no ashes to be carted away.

Tar as boiler fuel permits better maintenance of control over the rate of generation of steam. The fire can be started or stopped instantly. Smoke difficulties that so often prevail with bituminous coal as fuel are eliminated or reduced to a minimum.

When the tar is consumed at the plant where it is produced less fuel-storage space is required.

Less boiler-room labor is required.

If 100 gallons of tar of 17,000 B. t. u. per pound be considered equivalent, in actual operation, to 1 ton (2,000 pounds) of bituminous coal having a heating value of 12,000 B. t. u. per pound, the relative value of the two fuels at different prices can be quickly determined by referring to figure 6. This figure makes no allowance for savings that are possible by lower expenditures for labor and storage. As tar and its distillation products can be utilized for fuel, it is evident that any distillation fraction produced at the distillery for which there is no market can be disposed of to advantage. Here is an example: Assume that a gas plant producing both water-gas tar and coal-gas tar finds that it can not sell its water-gas tar but can sell its coal tar at a low price. Also assume that when the coal tar is distilled there is a good market for some of the distillates, creosote and naphtha, for instance, but no market for pitch or the other fractions. Under such circumstances the coal tar could be distilled, the crude naphtha and creosote recovered, and the other distillates and pitch mixed with the water-gas tar and the resulting tarry mixture burned as fuel. The income from selling the distillates must, of course, more than pay for the cost of distilling the coal tar.



a, Heat of combustion per pound of tar=15000 B. t. u.
b, Heat of combustion per pound of tar=17000 B. t. u.

FIGURE 6.—Relative value of coal tar and coal as boiler fuel, for tar with heats of combustion equal to 15,000 and 17,000 B. t. u. per lb. and 9½ lb. per gal., and for coal with heats of combustion equal to 12,000 B. t. u. per lb. No allowance is made for the difference in labor requirements, such as carting ashes or tending the boiler.

In burning tar the right kind of burner or nozzle should be used. Although a "home-made" burner devised by the fireman or engineer on the job may prove a success, such a burner is apt to be a failure. The writer believes that it is advisable to use a burner made and sold for use with heavy liquid fuel, one known to give satisfactory results.

The essential requirements for the successful utilization of tar as fuel are as follows:

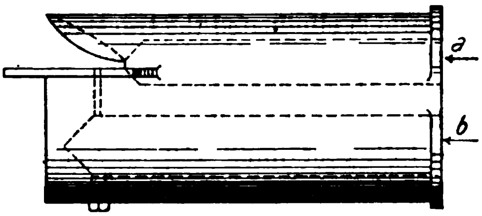


FIGURE 7.—Oil burner suitable for burning tar: *a*, Steam; *b*, tar.

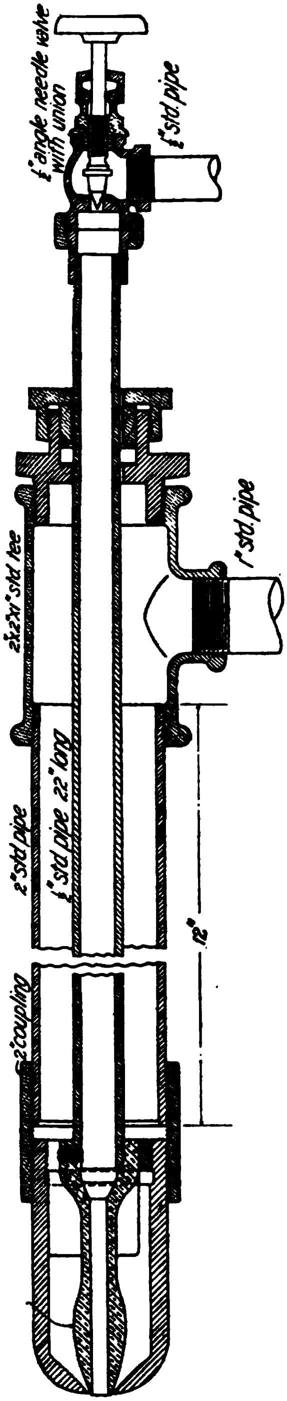


FIGURE 8.—Steese tar burner.

1. The tar must be injected into the fire box as a thoroughly atomized spray.
2. It should be strained and be free from particles that may clog the burner.
3. It must be warm enough to flow freely.
4. Air ports must be provided for supplying enough air to burn the tar completely.
5. The burner should be so designed that the fuel can not carbonize over and choke the atomizer slot; that the burner can be cleaned quickly without being removed and regulated quickly for different rates of fuel consumption.
6. When steam is the atomizing agent, provision should be made whereby only dry steam enters the burner.

Figures 7 and 8 show burners that are suitable for burning tar and have been used successfully with steam as the atomizing agent. Many other burners designed for liquid fuel are perhaps equally suitable for this purpose. Publications already mentioned in this paper contain detailed descriptions of them and their adaptability to different purposes.

TARRED FELT OR ROOFING FELT.

One of the early uses to which coal tar was put industrially was in the manufacture of roofing materials. Originally single sheets of millboard were coated with tar and painted with it after they were laid on the roof. Then came the treatment of large rolls of roofing felt, which eliminated the transverse joints on the roof. The present method consists in treating special felt paper with hot tar, and removing the excess of tar by passing the felt between heated steel rollers; from the rollers the felt is run on a spindle and made up into rolls containing 250 or 500 square feet. The rolls are then wrapped in paper and are ready for the market. It is often necessary to "age" and "turn" the finished product before marketing; that is, the paper rolls are stood on end and are turned, end for end, every few days for two or three weeks, in order to keep the paper at one end of a roll from becoming "soggy." Aging and turning are necessary because the paper sometimes has more tar on it than it can absorb at once. The use of heavy cold tar also aggravates the tendency of the paper to become soggy. Tar paper should always be stood on end when stored.

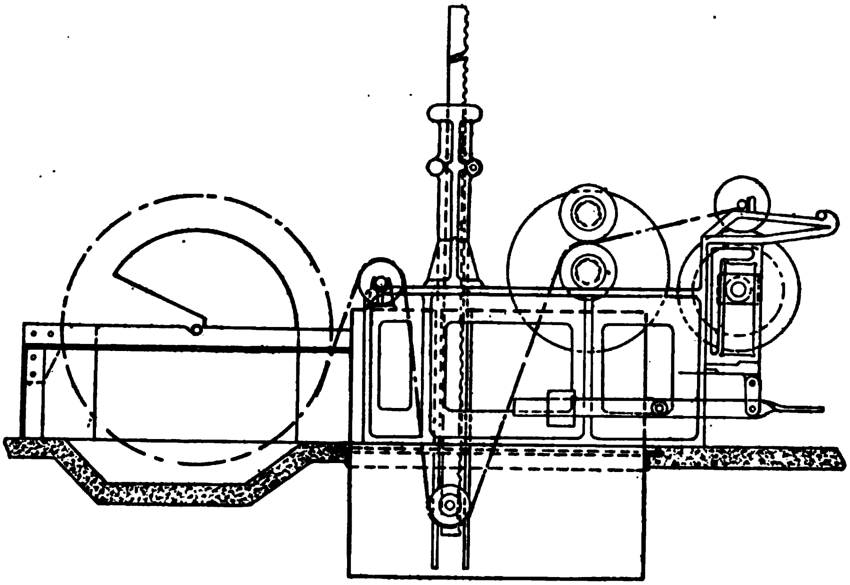


FIGURE 9.—Machine for saturating roofing felt.

One form of apparatus for treating felt is shown in figure 9. The raw felt, which is supplied in rolls varying in quality and thickness and weighing from 250 to 650 pounds, is suspended on a spindle from which it unrolls as fast as it is drawn through the hot tar.

The temperature, water content, and consistency of the tar used are of considerable importance in the manufacture of a good roofing felt. While the paper is being treated with tar it is under considerable tension, because the force required to unroll it, draw it through the tar, and roll it, is exerted at one end. If the tar contains water this is absorbed by the paper, which can not now withstand the stress and breaks or tears at the surface of the tar; consequently the tar must be free from water. Even if the paper did not break under these conditions, it is desirable that the tar should be freed of water before the felt is saturated, as the presence of water causes uneven saturation and impairs the waterproofness of the product. In order to insure a high saturation, the tar should be hot enough to reduce its viscosity and give it the consistence of a thin sirup. The limiting temperatures for the best results are 200° and 260° F.

The tar used for this purpose is sometimes prepared by distillation to a pitch and "cutting back" the pitch so obtained with creosote, or with creosote and light oil, and is called "prepared tar." It is preferable, as a rule, to use "straight" dehydrated tar, thinned, when necessary, with light oil or creosote that has been cooled and freed from naphthalene. When the natural tar is so high in naphthalene that the desired saturation can not be obtained without the naphthalene causing the layers of tarred felt in a roll to stick together, the "prepared tar" is preferable. Usually naphthalene is not present in such proportions, particularly not in "straight" coal tar.

Felt absorbs from 100 to 200 per cent of its weight of tar. When it is oversaturated, or when the excess of tar has not been removed by the rollers, the sticking of the convolutions of the tarred felt in a roll may make unrolling difficult or even impossible. If the felt is undersaturated, the finished product will be porous, capable of absorbing moisture, and therefore less waterproof. The degree of saturation is controlled by the time the felt is allowed to remain in contact with the tar, which may be governed by the depth of immersion, and the speed of travel through the tar.

The steam-heated rolls between which the felt passes (see fig. 9) prevent the paper from cooling too quickly, aid the absorption of the surface tar, and remove the excess tar. Saturated felt so prepared is employed chiefly for pitch and gravel roofs or as a basis for slate and tile roofs. It is sometimes used as building paper and as deadening felt and for waterproofing walls, tanks, and tunnels, where it is applied as on a roof.

A number of kinds of tarred roofing papers, differing mainly in degree of saturation and weight per square foot, are on the market. Soft thick felts absorb more tar per square foot than thin hard felts, and a roll of tarred soft felt is therefore heavier than a similar sized roll of tarred hard felt. Some of the more common saturated felts in general use are slaters' felt, made in two grades, weighing 30 and 40 pounds, respectively, per 500 square feet; and tarred felt, made in three grades, weighing, respectively, 60, 70, and 75 pounds per 500 square feet.

Heavier felts than these are made but are not in as wide demand.

PAINT FOR STONEWORK, BRICKWORK, AND IRON.

As an inexpensive coating for brick or stone work exposed to the action of acid vapors, alkalis, or the atmosphere, tar is a ready and satisfactory material. Although tar dries more slowly than some specially prepared pitch paints, it is used extensively as a paint. It should be dehydrated, and is usually applied hot.

Hot water-free tar is also used for painting underground iron pipes and for coating castings, pipe fittings, and metal roofs that are exposed to the atmosphere. It is not so resistive to the weather as specially prepared pitch paints (see p. 4), but it is a good preservative and answers the purpose well where an inexpensive coating must be used.

ROAD-CONSTRUCTION MATERIAL.

Tars and tar products are fast replacing mineral-oil products for surfacing roads. This fact may be variously ascribed to the increasing supply of suitable tars, the decreasing supply of suitable mineral-oil products, increased appreciation and recognition of the suitability of tars, and the more general availability of tars in practically all parts of the country.

Lunge[10] reports that in Great Britain in 1907 there were only 100 miles of road covered with tar or tarry mixtures, whereas in 1908 there were 700 miles; in 1909, 3,000 miles; and in 1910, 7,000 miles of such road.

A number of specifications have been drawn up for the tar to be used for this purpose, a fact not at all surprising in view of tars being produced under so many different conditions, and the roadbed, surfacing materials, and traffic and climatic conditions differing widely from place to place. Road tars are used for various purposes, and may be applied in different ways to obtain a particular result—a further cause for the wide variance in specifications. They may be used as a binder in place of cement, as in bituminous macadam roads, for dust-settling purposes or for cementing material—grouting—in the construction of brick, stone, or wood-block pavements. Although the material used for these purposes is usually either a soft pitch or a refined tar, or a mixture of the two, it is quite generally termed "road tar."

A bituminous material such as tar and pitch is used on gravel and crushed-stone roads in several ways: First, it may be forced into the interstices between the stone after it is placed on the road; second, it may be thoroughly mixed with the stone or gravel before the latter is placed on the road (care being taken to avoid using an excess of it); and third, it may be applied to the surface of a finished gravel or broken-stone road with or without a final topping of coarse sand or fine gravel. The pavement produced by the first method cited is called bituminous macadam; that produced by the second method is known as bituminous concrete.

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[10] Lunge, George, Coal tar and ammonia. London. 1916, 739 pp.

BITUMINOUS MACADAM.

On a subgrade, prepared by the usual method of grading, draining, and rolling, a base, or bottom course, of broken stone (1 to 3½ inch) is laid; after this has been rolled, a second course of broken stone, usually of somewhat smaller (1 to 1½ inch) size, is laid on top of it. The prepared "road tar" or pitch is forced into the interstices of the top layer, which is then covered with finely cut, one-fourth to three-fourths inch stone to fill all voids. After this surface is properly rolled, a final coat of similar bituminous material is applied, covered with fine gravel or screenings, and rolled. The pitch used for the top coat is softer than for the main binding material. The depth of each course is predetermined according to the kind and amount of traffic the road must bear. The binder is always applied hot—200° to 225° F.—and the amount used per square yard varies between 1¼ and 1¾ gallons, depending on the depth and on the size of stone. In preparing the final surface or "seal coat," one-third to three-fourths gallon of binder is used per square yard of road.

BITUMINOUS CONCRETE.

Bituminous concrete pavement is prepared much like concrete pavement, except that the binding material is a bituminous substance instead of Portland cement. A first course of crushed rock is put down as for bituminous macadam; on top of this is laid a layer of mixed crushed rock and sand that has been thoroughly mixed or coated with a bituminous material (pitch). This layer is applied and rolled while hot. The pavement may be left in this condition, but much of it is given a "seal coat" by spreading a layer of the bituminous material (usually thinner and of lower specific gravity than the main binder) over the surface, covering it with fine gravel or coarse sand, and rolling. The size of stone ranges from one-fourth to 1½ inches, according to conditions, but the custom is to use the larger sizes in the thicker pavements. One specification requires a mixture of 1 cubic yard of grit sand less than three-eighths inch and 3 cubic yards of broken stone, three-fourths to 1½ inches. The material must be thoroughly coated, during mixing, with the bituminous binder, and an appreciable excess of binder should be avoided. One specification requires that 18 gallons of it be used per cubic yard of stone, approximating 5 to 7½ per cent by weight in the finished pavement, but others require 25 to 30 gallons per cubic yard of material treated. The mixing is always done hot at 180° to 300° F. and the mixture is delivered at about 150° F.

SURFACING FOR OLD ROADS.

When old roads are repaired, it is often the practice to apply a "blanket" or "seal" coat to the surface after the necessary repairs are made. For this purpose, a heavy refined tar or soft pitch is suitable, and the amount used per square yard ranges from one-half to 1 gallon, according to the thickness of the coat and the condition of the surface to which it is applied.

ROAD PRESERVER AND DUST SETTLER.

In the maintenance of roads, it is desirable in many places to apply periodically a thin layer of bituminous material to the surface. For this purpose, refined tar is often suitable. The tar is preferably applied hot, but sometimes is applied cold, in which event it must, of course, be thinner than a soft pitch in order to spread properly. Less than a gallon per square yard is used, and ordinarily but 0.2 gallon.

Such a coat retards the formation of dust. For this purpose, tar is superior to many of the oils that are sometimes recommended and sold as dust preventives. Prof. Agg[11] says that in oiling roads "there is some danger of introducing into the surface an oil that will act as a lubricant instead of as a binder, and in that event the road will become loose and rapidly develop pot holes and ruts under traffic. Considerable difficulty has been experienced throughout the United States from that source, and too much emphasis can not be put on the importance of using a good asphaltic base oil or a suitable grade of tar." It is undoubtedly true that tar has less lubricating qualities and contains a greater proportion of bitumens—binding material—and has greater antiseptic and germicidal properties than most mineral oils. Consideration of the foregoing statements will indicate how prominent tar is to be as a road material; moreover, statistics show that the yearly production of coal tar is rapidly increasing, whereas the demand for mineral oils is growing faster than the supply, with prospects of higher prices. Tar is now sold at many works at a lower price per gallon than good mineral oil (road oil).

FACTORS RETARDING THE MORE EXTENSIVE USE OF ROAD TAR.

General utilization of tar for road building and surfacing has been retarded by the promiscuous use of any and all grades of tar on all sorts of roads, without regard to climatic conditions or the condition of the road. Obtaining the best results requires the use of judgment. Special care should be taken that tar is not applied to wet or frozen roads and that it is hot enough to be of the consistency most suitable for the particular road treated. When tar is spread thickly, under conditions that do not permit ready absorption, it may be spattered on automobiles and other vehicles to such an extent as to cause prejudice against all tar pavements. After crossing such a street afoot, people with white shoes are not apt to have a very kindly feeling toward tar as a road-surfacing material.

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[11] Agg, T. R., The construction of roads and pavements. New York. 1916, 432 pp.

The best results are obtained when the road to be treated is dry, free from dust, and warm, and the tar used is water-free and hot.

SPECIFICATIONS FOR ROAD TARS.

Specifications for these tars are made with the following intentions:

1. To avoid adulteration or dilution with inferior products.
2. To insure a bitumen content high enough for the purpose.
3. To reduce lubricating properties to a minimum.
4. To provide for the use of tars of the proper consistence only.
5. To avoid the use of tars that will cause rapid deterioration of the road.

As a complete discussion of the merits or defects of the various tars can not be presented here, only their principal requirements are mentioned.

The specific gravity of a pure crude tar has considerable significance to a chemist and is one of the factors governing purchase; however, as mixing very light oils with pitch will yield a tarry mixture of any intermediate specific gravity, the specific gravity alone is not a reliable test. To prohibit this "cutting back" of pitch with light oils that are volatile and undesirable in a road tar, the loss on heating a sample to a given temperature in a distillation apparatus is limited to a given maximum. The addition of mineral oils is guarded against by stating the specific gravity of the fractions obtained on distillation, or by chemical tests. The specific gravity of high-boiling fractions from the distillation of coal tar is greater than 1.00, whereas the specific gravity of mineral fractions is less than 1.00. To insure a high enough bitumen content, the percentage of distillation residue above a defined temperature and the percentage of free carbon are limited. The lubricating properties are avoided by employing only those tars that do not contain any appreciable amount of paraffin oils, namely, tars of high specific gravity—coal tars. Specifications also consider the fluidity (viscosity) of the tar at a given temperature and require that the tar be applied at the most suitable temperature.

Much has been said regarding the free carbon and the naphthalene content of road tars. Some difference of opinion exists as to the maximum amounts permissible and as to the minimum amount of free carbon that will be tolerated. It is generally agreed that a great excess of either naphthalene or carbon is detrimental, and should not be allowed. Tars with very small content of free carbon are frequently inferior to those with a moderate content. The upper limit sometimes set for the free carbon content of tars used as binder is 25 per cent and the lower limit is frequently 12 per cent. For hot surfacing the limits are 22 and 10 per cent. Sample specifications for road tars for various purposes are given in Table 4.

TABLE 4.—*Specifications for tars.*

FOR BITUMINOUS CONCRETE.

[Standards adopted Oct. 14, 1916, by American Society of Municipal Improvements.]

Items.	Water-gas tar.	Coal tar.
1[a]. Shall not foam at........° C..	150	150
2. Specific gravity at 25° C. (77° F.)........	1.16 to 1.20	1.20 to 1.30
3. Viscosity by New York float apparatus........seconds..	140 to 170	140 to 170
4. Bitumen soluble in carbon bisulphide, not less than........per cent..	95	75 to 90
5.[b] Distillation yield to 170° C. (338° F.) not more than........do....	0.0	0.0
Distillation yield to 270° C. (518° F.) not more than........do....	7.	10.
Distillation yield to 300° C. (572° F.) not more than........do....	20.	20.
6. Distillate, total, specific gravity at 25° C........	1.00 to 1.02	1.03
7[c]. Distillation residue, melting point of, not more than........	75° C.(167° F.)	75° C.(167° F.)

FOR BITUMINOUS MACADAM.

[Standards adopted Oct. 12, 1916, by American Society of Municipal Improvements.]

Items.	Water-gas tar.	Coal tar.
1.[a] Shall not foam at........	121°C.(250°F.)	121°C.(250°F.)
2. Specific gravity at 25° C. (77° F.)........	1.15 to 1.20	1.18 to 1.30
3. Viscosity by New York float apparatus........seconds..	120 to 150	150 to 180
4. Bitumen soluble in carbon bisulphide, not less than........per cent..	95	80 to 95
5. Distillation yield to 170° C. (338° F.) not more than........do....	0.5	0.5
Distillation yield 0 to 270° C. (518° F.) not more than........do....	12.0	10.0
Distillation yield 0 to 300° C. (572° F.) not more than........do....	25	20
6. Distillate, total, specific gravity........	0.98 to 1.02	1.02
7. Melting point of residue, not more than........	75° C. (167° F.)	75° C. (167° F.)

[a] This test signifies that the water has been removed, as tars that contain water foam on being heated.

[b] Distillation is made according to the 1911 tentative specifications of the Society for Testing Materials. 100 c. c. of tar is distilled in an Engler flask, the thermometer bulb being at the offtake arm.

[c] The melting point is determined by the cube method.

Specifications for joint-filler "tar" (pitch) for wood blocks, stone, or brick.

Pitch, straight run from coal tar:

Specific gravity at 78° F........	1.24 to 1.32
Melting point ....° F....	115 to 150
For mastic filler........do....	115 to 135
For brick and stone blocks........do....	125 to 140
For wood blocks........do....	140 to 150
Free carbon (per cent)........	Not less than 22 nor more than 37.

Distillation.—The specific gravity of the distillate at 670° F. shall not be less than 1.07 at 140° F. compared with water at that temperature. The distillation is made in an 8-ounce retort. The amount of oil distilling up to 670° F. in this method is approximately the same as distills up to 314° C. in the flask method.

REQUISITES FOR ROAD-DUST SETTLERS.

The very light tars are most suitable for road-dust settlers. The free carbon should be very low, the lower the better, usually, and water and naphtha should be removed. Water-gas tars are good for this purpose. As the surface on which the tar is to be applied must be considered, it is evident that specifications might require anything from a crude to a highly refined or specially prepared tar. The following requirements are representative for a coke-oven tar, water-gas tar, or other tars low in free carbon:

Specifications for light tar for road-dust settler.

Specific gravity 25°/25° C		1.10 to 1.14
Specific viscosity, at 40° C		25 to 35
Total distillate by weight (flask distillation):		
To 170° C. not more than	per cent	2
Total up to 270° C. not more than	do	25
Total up to 300° C. not more than	do	35
Free carbon, not more than	do	5

To be applied hot or cold (but preferably hot), using one-third to one-half gallon per square yard for first application and one-tenth to one-fifteenth gallon per square yard for subsequent applications.

Frequent changes in specifications have resulted from the experiments that are being carried on continually with various tar preparations. Specifications for such materials that have been used with success have been published by the U. S. Department of Agriculture.[12] These are not represented as "standard" but as "typical" specifications. In general a tar from which the fraction boiling below 150° to 170° C. has been distilled off makes a suitable material for a primer or surface coat on macadam, gravel, or shell roads, especially if the tar contains a rather low percentage of free carbon. High-boiling fractions are sometimes added to increase the fluidity of the product and decrease its content of free carbon. Methods of "meeting" specifications are mentioned in a later section of this paper.

When surface coats and dust preventives are applied care should always be taken to see that the road is dry and free from accumulations of dust and dirt. It is best to sweep the road clean before treating it.

WATERPROOFING AND ROOF PAINT.

Coal tar and water-gas tar, when free from water, make excellent paint for shingle roofs, being good, of course, as black paint only; but roofs painted with these tars look rather like slate and do not retain an undesirable jet black appearance. Retarring does not have to be done as often in order to keep the roof in repair. Tar should be applied when a roof is dry and preferably when it is warm, as when it is exposed to the direct rays of the sun. A greater penetration is obtained by using a tar of low free-carbon content and applying it hot or warm.

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[12] Hubbard, Prévost, and Reeve, C. S., Typical specifications for bituminous road materials: Bull. 691, U. S. Dept. of Agriculture, 1918, 60 pp.

As a protective coating, or for renewing the freshness of a "patent" roof (one covered with prepared roofing paper), dehydrated tar is inexpensive. Although it can not be as highly recommended as a specially prepared pitch paint, discussed on page 46, it is much used.

Whenever a cheap paint with waterproofing qualities is required for coating cement, stone, or brick walls or the like, the color being inconsequential, tar may be suitable. It should be free from water, and if it is very viscous should preferably be applied hot. The less light oil it contains the greater is its value for this purpose.

GERMICIDE.

Although tar is not as widely used as a germicide as some of the products obtained from it by distillation and other means, still its value for some purposes is worth considering. Other things being equal, this germicidal property alone should give tar preference over mineral oils as a road-dust settler. It increases the value of tar as a paint for special places, as the interior of chicken houses, pens for small animals, stables, barns, and bunk houses. When mixed with tar oils it is used as a wood preserver.

MISCELLANEOUS USES.

Relatively small quantities of tar are consumed annually for many minor uses. It is used in special paints and varnishes, prepared cements, special waterproofing mixtures for cloth, felt, wood, and cement, patent fuels, smudge fuels for use in orchards, manufacturing gas, and special preservative preparations.

CRUDE DISTILLATION PRODUCTS OF TAR.

Many of the crude distillation products of tar are used raw, either alone or mixed with others. The demand for them is not relatively proportional to the production of each, therefore there is frequently a surplus of some one or more for which it is not easy to find a market. Some of these products are discussed in the order given herewith:

1. Ammonia water (ammoniacal liquor).
2. Crude naphtha.
3. Light oil.
4. Crude carbolic oil (middle oil).
5. Creosote oil.
6. Anthracene oil.
7. Pitch.

AMMONIA.

Tar from the works often contains 3 to 10 per cent of water, but this amount is reduced to about 2 per cent on settling. The water that is taken off the top of the tar is not pure, but contains ammonia and ammonium salts, and is known as ammoniacal liquor. When heat is employed to facilitate settling and tanks used are open, much of the ammonia is expelled and lost. Ammonia is also liberated in the early stages of distillation with the remaining water and the crude naphtha. It may be recovered by proper methods of condensation. In small works the recovery of ammonia is not attempted, but in the larger distilleries recovery is common practice. The liquor recovered seldom contains more than 2½ to 3 per cent ammonia and often much less. No ammonia is produced in the manufacture of water gas, hence no ammonia or ammoniacal liquor accompanies water-gas tar, although the writer has found, during experiments in the use of bituminous coal as water-gas generator fuel, that ammonia is produced during the process of gas making. The liquor is not worked up at the tar works but is usually sold to an ammonia-refining company.

CRUDE NAPHTHA.

Crude naphtha is used in shingle stains, in cheap paints for outside use, as a solvent for pitch in the preparation of metal paint and roof paint, and in the preparation of special so-called varnishes. It is an excellent solvent and could be used crude in paint or as a paint and varnish remover, except for its strong odor.

LIGHT OIL.

Light oil is not used as much in the crude state as the other fractions are. It frequently contains naphthalene, some of which crystallizes from solution in cold weather. This fraction is used as light creosote in shingle stains, as a solvent in the preparation of roof paints and some metal paints, and as a fuel oil and as fuel in mixtures with pitch. Considerable light oil was formerly sold, mixed with heavy oils, as creosote, but when creosote is purchased in large quantities the specifications usually preclude such a mixture.

Coal tar is sometimes distilled in the usual way and the resulting pitch is "cut back" with light oils and water-gas tar and the resulting mixture used as fuel tar; thus the most valuable products are recovered, while the pitch, light oil, and any other surplus product is utilized as fuel. Refined coal tar is sometimes made similarly by "cutting back" pitch with tar oils consisting chiefly of light oil.

CRUDE CARBOLIC OIL (MIDDLE OIL).

Middle oil contains most of the carbolic acid and a large proportion of the naphthalene originally present in the tar. On cooling the naphthalene crystallizes and is readily separated from the oil. The latter is used in the preparation of disinfectants and germicides, and is sold raw for such purposes. There is a decided difference between crude carbolic oil and crude carbolic acid, although in some parts of the country the former is being sold under the name "crude carbolic acid." The latter, which is a product extracted from the crude oil, is mentioned on page 59.

Middle oil is also used in mixtures with the heavier fractions as a wood preservative, the mixtures being sold under the name of creosote or creosote oil.

CREOSOTE.

There is some confusion regarding the meaning of the word creosote. The definition given in Webster's dictionary is:

> *a.* An oily antiseptic liquid, of a burning smoky taste, colorless when pure, but usually colored yellow or brown by impurity or exposure, obtained by the distillation of wood tar, especially that of beechwood. It is a complex mixture of various phenols and their ethers, the principal constituents being guaiacol, creosol, phlorol, and methyl creosol. *b.* A similar substance obtained from coal tar.

The definitions given for creosote oil are:

> *a.* That part of the wood-tar distillate from which creosote is obtained by purification. *b.* The third main fraction in the distillation of coal tar, boiling from 230° or 240° to 270° C. It is a greenish yellow oil, heavier than water, containing phenols and other bodies.

From the last definition, creosote oil is the fraction distilling just after the carbolic oil and before the anthracene oil. As frequently used, however, the term has a broader application, including all the heavy oils distilling up to the temperature at which soft pitch remains in the still. Sometimes "creosote oil" means carbolic oil; then the true creosote oil is called heavy oil. Of late years tar has been added to creosote oil and carbolic oil, and the mixtures are sold as creosote, creosote oil, wood preservers' creosote, and paving-block oil, for treating timbers and wood blocks. It is accordingly not surprising that so-called creosote oil can be purchased having almost any specific gravity from 1.02 to 1.14.

Specifications for creosote oil differ so widely that the term frequently means a tar oil with a specific gravity greater than water and with a high boiling point. The word creosote is often used as synonymous with creosote oil.

True creosote oil, which comes over after the carbolic fraction, usually contains naphthalene that may crystallize on cooling.

Usually the naphthalene is not separated from the liquid, as the oil is mainly used in wood preserving, for which purpose a small content of naphthalene is not objectionable.

The two primary objects of treating timbers and wood blocks with creosote oil are to preserve the wood from decay caused by the action of molds and fungi, and to waterproof the wood to prevent warping and swelling.

Numerous experiments with the various tar oils as wood preservers have demonstrated clearly that the heavy fractions from the distillation of coal tar are superior to the light fractions or to mixtures of the light with the heavy. It has been shown[13] that the light oils boiling below 205° C. (401° F.) do not remain long in treated timber, whereas the heavy oils with a high content of anthracene oil remain almost indefinitely and preserve the wood from decay and from boring animals. Table 5 gives analyses of oils extracted from preserved wood after years of service. The fractional distillations were made in a glass distillation flask with the thermometer bulb at the side neck. The tar acids remaining after years of service amount to less than 1 per cent.

TABLE 5.—*Analyses of extracted oils.*

Samples.	Average service.	Creosote per cubic foot.	Distillation of extracted oil.								
			To 205° C.	205 to 245° C.	245 to 270° C.	270 to 320° C.	320 to 420° C.	Residue above 420° C.	Solid naphthalene from distillates.	Solid anthracene oil from distillates.	Tar acids.[a]
	Yrs.	*Lbs.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*C. c.*
19 cross ties	21.84	9.58	0.025	12.07	13.88	23.80	24.69	25.27	1.19	23.47	0.65
6 English piles	43.0	9.19	.46	16.92	15.31	21.06	22.77	23.04	....	19.95	.61
6 American piles	20.2	15.64	.57	30.28	15.82	18.49	13.21	21.43	25.93	43.27	....
4 paving blocks	23.6	15.70	.29	21.34	21.39	18.73	19.40	18.64	12.52	40.40	.52
1 paving block, poor service	9.0	5.77	9.62	14.41	19.27	41.74	11.23	3.40	....	....	....
1 conduit pipe	14.0	8.74	5.08	27.23	10.46	27.68	19.03	9.93	23.17	14.28	....
Average of 36 timbers giving good service	24.9	11.18	.36	17.37	15.18	22.0	21.71	23.09	6.98	27.81	.50

[a] The results for tar acids are expressed as cubic centimeters in 100 c. c. of extracted oil, and therefore represent the percentage by volume of tar acids in the oil.

The method of applying creosote, the quantity used per cubic foot, and the grade most suitable depend on the kind and condition of wood to be treated and the use to which it is put. When the wood is merely dipped, as in the open-tank process, the loss of oil by evaporation is proportional to the temperature of the bath, to the percentage of low-boiling oils present, and to the area of the exposed surface of the bath. With this method, an oil that has the minimum content of low-boiling constituents is particularly desirable; it should not contain an appreciable amount of free carbon. The wood will absorb only a small amount of oil when treated by this process, even under the best conditions; therefore an excessive proportion of high-boiling solids that may on chilling choke the pores of the wood during treatment is undesirable. Very often, however, tar of low free-carbon content is mixed with tar oils for use in this process, cost being the controlling factor.

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[13] Alleman, Gillert, Quantity and character of creosote in well-preserved timbers: U. S. Forest Service Circular 98, 1907, 16 pp.

In the closed-tank or pressure processes, considerably more creosote oil is used per cubic foot of wood treated, the amount ranging from 5 to 20 pounds in different specifications. A common requirement for paving blocks for exposed pavement is that the penetration be equivalent to 16 pounds of water-free oil per cubic foot of wood.

The oil used for this and similar purposes may be classed, first, as a pure distillate of coal tar, and, second, as mixtures of such distillates with pure water-free coal tar. A few sample specifications for such oils follow:

The city of Chicago specifies the following requirements for oil for the treatment of wood paving blocks.

SPECIFICATIONS FOR OIL FOR TREATING WOOD PAVING BLOCKS.

1. The oil shall be a distillate obtained wholly from coal tar.

2. It is required by this specification that the oil used shall be wholly a distillate oil obtained only by distillation from coal tar. No other material of any kind shall be mixed with it.

3. The oil shall contain not more than 1 per cent of matter insoluble in hot benzol and chloroform.

4. Its specific gravity at 25° shall be not less than 1.08 and not more than 1.12.

5. The oil shall be subject to a distilling test as follows:

The apparatus for distilling the creosote must consist of a stoppered glass retort having a capacity, as nearly as can be obtained, of 8 ounces up to the bend of the neck, when the bottom of the retort and the mouth of the offtake are in the same plane. The bulb of the thermometer shall be placed one-half inch above the liquid in the retort at the beginning of the distillation, and this position must be maintained throughout the operation. The condensing tube shall be attached to the retort by a tight cork joint. The distance between the thermometer and the end of the condensing tube shall be 22 inches and during the process of the distillation the tube may be heated to prevent the congealing of the distillates. The bulb of the retort and at least two inches of the neck must be covered with a shield of heavy asbestos paper during the entire process of distillation, so as to prevent heat radiation, and between the bottom of the retort and the flame of the lamp or burner two sheets of wire gauze each twenty mesh fine and at least six inches square must be placed. The flame must be protected against air currents.

The distillation shall be continuous and uniform, the heat being applied gradually. It shall be at a rate approximating one drop per second and shall take from thirty to forty minutes after the first drop of distillate passes into the receiving vessel. The distillates shall be collected in weighed bottles and all percentages determined by weight in comparison with dry oil. When one hundred grams of the oil are placed in the retort and subjected to the above test, the amount of distillate shall not exceed the following:

Percentage of distillates from oil for wood paving blocks.

	Per cent.
Up to 150° C.	2
Up to 210° C.	10
Up to 235° C.	20
Up to 315°	40

The distillation of the oil shall be carried to 355° C. The residue thus obtained when cooled to 15° C. shall not be brittle, but shall be of a soft, waxy-like nature so that it can be readily indented with the finger. When a small portion of this residue is placed on white filter paper and warmed, the oil spot produced, when viewed by transmitted light, shall appear of an amber color.

6. The tar acids of the distillate from 250° C. to 315° C. must not be less than 6 per cent of this distillate (250° to 315° C.).

7. The amount of the unsaponifiable oil (by sulphuric acid and caustic soda) in the distillate from 250° C. to 315° C. must not exceed 3½ per cent of this distillate.

The following is the American Railway Engineering Association specification for creosote oil:[14]

TABLE 6.—*Commercial creosote-oil specifications.*

	Grade 1.	Grade 2.	Grade 3.
Distillation:[a]			
Below 210° C., not over . . . per cent. .	5	8	10
Below 235° C., not over . . . do. . . .	25	35	40
Residue above 355° C. must be soft and greater than . . . do. . . .	5	5	5
Water, not over . . . do. . . .	3	3	3
Specific gravity at 38° C., not less than . . .	1.03	1.03	1.025

[a] Distillation results are calculated on the basis of dry oil when distilled by the method adopted by the Am. Ry. Eng. Asso. in an 8-ounce asbestos-covered retort, with standard thermometer and bulb one-half inch above the surface of the oil. Per cent here means per cent by weight.

Grade 1 is a pure product obtained from coal-gas tar or coke-oven tar, and shall be free from any tar, or from any oil or residue obtained from petroleum or any other source; it shall be completely liquid at 38° C. (100° F.) and shall be free from suspended matter. Grades 2 and 3 shall be the best obtainable grades of coal-tar creosote.

The specifications for creosote oil prepared by a committee on standard specifications for creosoted wood-block paving of the American Society of Municipal Improvements are given in Table 7.

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[14] American Wood Preservers' Asso., Handbook on wood preserving. Baltimore. 1916, 73 pp.

TABLE 7.—*Specifications for wood-preserving oil.*

	Grade A.	Grade B.
Water..................per cent..	Not more than 3	Not more than 3.
Matter insoluble in benzol..do....	Not more than 3	Not more than 0.5.
Specific gravity at 38° C.	1.07 to 1.12	Not less than 1.06.
Distillates:		
Up to 210° C........per cent..	Not over 5	Not over 5.
Up to 235° C..............do....	Not over 25	Not over 15.
Residue above 355° C.	If over 35 per cent shall have a float test of not over 80 seconds at 70° C.	If over 10 per cent shall have a float test of not over 50 seconds at 70° C.
Specific gravity, fraction 235 to 315° C.	Not less than 1.02 at 38/15.5° C.	Not less than 1.02 at 38/15.5° C.
Coke residue............per cent..	Not more than 10	Not more than 2.

Grade A is a coal-tar paving oil, a coal-tar product at least 65 per cent a distillate of coal-gas tar or coke-oven tar, the remainder refined or filtered coal-gas tar or coke-oven tar.

Grade B is a coal-tar distillate oil, a pure distillate of coal-gas tar or coke-oven tar.

It is to be noted that water-gas tar or products therefrom are not considered suitable for preserving wood. The advisability of including this tar or its products as a permissible preservative in mixtures of coal-tar creosote can not be discussed here, although it is mentioned later in discussing the properties of water-gas tar from bituminous coal.

Creosote oil is also used as a "flotation oil" in the flotation process for separating certain ores, notably sulphide ores, from the gangue mineral associated with them, the particles of finely ground ore being floated on a froth created by agitating the ore in water containing the flotation oil in amounts ranging from 0.3 to 3 per cent by weight of the ore treated. Agitation is accomplished by mechanical means, by aeration, or by both, and flotation by the employment of oil, oil and acid, or by mixtures of oil and tar. The acid-tar oils—carbolic oil and creosote oil—have been successfully used, as well as mixtures of 10 per cent tar with varying amounts of wood-creosote oil and coal-tar creosote oil.

Creosote oil is also used in the preparation of disinfectants, sheep dips, germicides, shingle stains, and bituminous paints. It is seldom used as fuel because there is usually a ready market for it for other purposes.

ANTHRACENE OIL.

Anthracene oil is the last fraction from the distillation of coal tar. A considerable part of this fraction is solid and greasy when separated by itself. It has been used abroad to make cheap lubricants and cart greases, but is not, to the writer's knowledge, used for that purpose here to any appreciable extent. The value of the high boiling fractions as wood preservatives has already been pointed out, hence the reason for including anthracene oil with the creosote-oil fraction as a wood-preserving oil is evident. This is the chief use for this fraction in the crude state.

PITCH.

The properties of the residue—pitch—remaining in the still after distillation is complete depends, for any given tar, on the final temperature of distillation. If the maximum temperature reached in the still is less than 275° C., the pitch is very soft; that is, its consistence is such that a piece will stick to the teeth when chewed. When the distillation is continued up to 300° C., the resulting pitch can be chewed like gum, and will not stick to the teeth. When the distillation is carried further, however, the pitch becomes harder, the residue over 320° C. usually being so hard that it crumbles when an attempt is made to chew it. The free-carbon content of the tar also has much to do with the consistence of the residue remaining above a given temperature, hence the temperature limits just given are correct for certain tars, and are used here to emphasize the effect of temperature on the properties of the residue. The exact temperature limit of a tar distillation to produce a pitch of a specified consistence can best be determined by first distilling a small quantity in the laboratory. It frequently helps, in finishing the distillation, to draw samples of the residue from the still toward the end of the run.

Pitch is recognized as a suitable material for roofing. The well-known pitch and gravel roof is approved by the laboratories of the National Board of Fire Underwriters as a fire retardant roof. Architects and engineers generally recognize its merits. Its resistance to atmospheric conditions and to moisture are of prime importance. This roof consists of several—usually three to five—layers of tarred felt cemented together by mopping hot pitch over each layer when in place. A heavy coat of pitch is applied on top of the final layer, and is immediately covered with very fine gravel, or sand and gravel. This kind of roof is suitable for so-called "flat-top" buildings, those where the pitch or slope of the roof is not very great. The roofing pitch used for this purpose is medium to soft, according to the climate. Most roofers prefer a pitch that can be chewed between the teeth without crumbling. In this condition it can readily be broken into small pieces without sticking to the instruments used. It is decidedly common practice for the roofers to cut back the pitch a little by putting a small quantity of tar in the kettle with it. In fact, some roofers take advantage of the fact that tar is cheaper than pitch by buying as hard a grade of pitch as they think they can use and cutting it back with coal tar to the consistence desired.

The waterproofing qualities of pitch are utilized in a similar way in tunnels, on concrete retaining walls, reservoirs, tanks, and bridges. Soft pitch is also used as a road binder and is commonly called "road tar" or "paving tar"; its properties and its use for this purpose have been discussed. In addition, it is an ingredient of bituminous paints for metal roofs and masonry work.

Pitch mixed with coal has been used in the manufacture of coke, being used in amounts up to 5 per cent of the coal carbonized. Occasionally the quality of the coke is said to be considerably improved by the addition of the pitch.

As a binder in briquetting fuel, such as coal, coke breeze, and sawdust, both coal-tar pitch and water-gas pitch are satisfactory. They are not employed much for this purpose at present in this country, although the prospects favor considerably more pitch being so used in the future. Much experimental work has been done in briquetting various fuels and the requisite properties of a suitable binder have been demonstrated.[15]

Numerous other uses for pitch have been developed in patent processes and otherwise that utilize its cementing or waterproofing properties, as in flume cement, roof cement for patent roofings, expansion-joint filler, binder in the manufacture of special insulating and waterproof pipe, and insulation on dry cells and batteries. It is also used in producing "pitch coke" or "tar coke," which is mentioned on page 71.

COMMERCIAL PRODUCTS PREPARED FROM CRUDES.

Many of the products obtained from tar by distillation are sold and used in the crude state. The crude fractions are used alone, mixed with other fractions, mixed with pitch, or as an ingredient or component part of some manufacture containing materials other than tar products. The preparation of these products does not necessarily require great skill nor very elaborate equipment. Formulas and methods of preparing a number of them are given in the following order:

1. Metal paint.
2. Roof paint:
    a. For prepared roofs.
    b. For shingle roofs.
3. Pole and post paint.
4. Shingle stain.

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[15] Wright, C. L., Briquetting tests of lignite at Pittsburgh, Pa., 1908–9, with a chapter on sulphite-pitch binder: Bull. 14, Bureau of Mines, 1911, 64 pp. Mills, J. E., Binders for coal briquettes: Bureau of Mines, 1911, 56 pp. Wright, C. L., Briquetting tests at the United States fuel-testing plant, Norfolk, Va., 1907–8: Bull. 30, Bureau of Mines, 1911, 41 pp. Wright, C. L., Fuel-briquetting investigations, July 1904, to July, 1912: Bull. 58, Bureau of Mines, 1913, 277 pp.

5. Roof cement.
6. Flume cement.
7. Disinfectants and insecticides:
    - *a.* Sheep dip.
    - *b.* Water soluble disinfectants.
    - *c.* Powdered disinfectants.
8. Wood preserving oils.

METAL PAINT.

A highly satisfactory metal paint can be prepared by dissolving pitch in the light oils obtained in the distillation of tar. Many specifications require that such a paint should dry quickly; then the lightest oil, crude naphtha, is employed as a solvent. A very hard pitch will not dissolve readily in that oil. For this and other reasons it is more satisfactory to use a medium grade of pitch. The consistence must be such that the paint will flow well under the conditions prevailing at the time it is used. However, as the light oils evaporate readily and mostly do not remain in the paint film, the more oil used per unit of pitch the thinner will be the coat or film of paint. A formula for a metal paint that will flow well and can be applied with a brush at ordinary temperatures is: Medium soft pitch, 40 gallons; crude naphtha (from tar), 60 gallons.

A convenient way of preparing this paint is to use the fresh hot pitch before it has solidified. Draw off the desired amount of pitch in a kettle and then add the oil slowly and with constant stirring. When a paint of requisite consistence is obtained, it is well to determine with a hydrometer the specific gravity at a definite temperature in order that subsequent batches can be prepared like the original. It is preferable to have some of the higher boiling oils present in such paint, but these oils are not suitable when quick drying is essential and the paint must be applied cold.

Paint prepared according to the formula given is very elastic, but this elasticity is not permanent. On surfaces exposed to atmospheric conditions and to the sun, the paint film gradually becomes brittle. The time required for brittleness to develop depends, in part, on the free-carbon content of the paint. A paint having a moderately low free-carbon content is superior to one of a high content. Finely ground opaque pigments are sometimes used in bituminous coatings with the intention of excluding the actinic rays of light which play an important part in the decomposition of such coatings. The paint withstands high temperatures fairly well and is accordingly well adapted for use on stacks and boiler fronts; it is also particularly adapted to use underground, in tunnels and on pipe.

When the paint can be conveniently applied warm or to a warm surface, light oil may be substituted for crude naphtha to good advantage. Similarly, when castings and fittings are "dipped," it is desirable to use light oil as a solvent and to employ a warm bath. Closed steam is preferable to a direct fire for heating the paint bath.

By the addition of certain resins and linseed oil, the latter in proportion varying from 15 to 25 per cent, a paint may be prepared with somewhat better weathering properties, but its cost is higher.

ROOF PAINT.

For shingle roofs, a black paint is made similar to the metal paint, but naphtha is not, and should not be, employed as a solvent. In fact, it is better not to distill the tar to pitch but merely until the creosote oil fraction starts to come over. The refined tar so produced may then be "cut back" with creosote oil until the consistence is such that the paint flows freely from the brush. A minimum content of free carbon assures the deepest penetration of the paint into the wood; therefore, for this purpose a tar low in free carbon is superior to one with a high content of free carbon, other things being equal. The quantity of oil and pitch or refined tar used will depend on the specific gravity of each and on the degree of fluidity desired in the paint. On the assumption that the paint is to be made from pitch and oil of the specific gravities 1.20 and 1.04, respectively, and is to have approximately 1.08 specific gravity at 60° F., the quantities required to make 100 gallons are: Pitch (1.20 specific gravity), 25 gallons; tar oil (1.04 specific gravity), 75 gallons.

If refined tar with a specific gravity of 1.16 is used with a lighter oil as solvent and thinner, the proportions may be as follows:

	Gallons.
Refined tar (specific gravity, 1.16)	50
Tar oil (specific gravity, 1.00)	50
Paint (approximate specific gravity, 1.08)	100

When a thinner paint is desired, proportionally more oil will be required.

A shingle roof should be thoroughly dry before it is painted, for if it is some of the paint will be drawn up into the shingles beyond the overlapping joint, a place that can not be reached with a brush. As it is along such joints that the shingles decay first, the importance of this precaution is evident. A roof coated with this paint does not retain a jet black appearance, but a slate color that usually is preferable.

In such a paint the waterproofing qualities of the bitumens are added to the strong preserving properties of the tar oils, making a very desirable combination. It is absorbed by the wood to a great extent rather than left entirely as a film on the surface, and might with some propriety be termed a stain. Stains, mentioned later in this paper, do not include the heavier bodied tar or pitch mixtures.

Roof paint for "patent roofs"—roofs covered with specially prepared roofing paper—is not made in this way, yet does not differ much. In the discussion of metal paint (see p. 45) attention has been drawn to the fact that bituminous materials are affected deleteriously by exposure to the sun and by atmospheric conditions. The same disintegration takes place in roofing materials, which become hard and brittle simultaneously and are said to have lost their "life." The application of a bituminous paint at intervals freshens the roofing and prolongs its usefulness. As one would naturally suppose, such a paint must be heavy "bodied" and have a rather high content of bitumen.

Although it is not uncommon to find ordinary coal tar used for this purpose, the better way to prepare a satisfactory roof paint is to "cut back" a soft pitch with an oil free from naphthalene. Light oil is suitable. A lighter oil would perhaps make the paint dry quicker, but quick drying is not essential nor particularly desirable. The heavy oils make a slow-drying paint. A suitable pitch paint may be prepared by adding light oil slowly to melted pitch while the mixture is being constantly stirred. The following amounts have been used in a paint that seemed to fill the requirements: Soft to medium soft pitch, 75 gallons; light oil, 25 gallons.

The specific gravity of this paint is approximately 1.15. Mixtures of the same specific gravity do not have the same viscosity or fluidity; in other words, the fluidity of mixtures made to a specific gravity of 1.15 is not the same, regardless of the kind and quality of the pitch and oil used. Hence a paint of 1.15 specific gravity may have the desired consistence in one purpose, but it may be either too heavy, too viscous, or too thin for another. It is best to make a standard paint from the materials available and prepare subsequent batches similar to it.

A prepared paint always sells at a higher price than tar, and it is therefore not surprising that painters and roofers sometimes add rather large quantities of water-free tar to the paint.

POLE AND POST PAINT.

Unlike wood-preserving oil, pole and post paint is seldom purchased in large quantities; therefore, rigid specifications for it are rare. Accordingly, it sometimes happens that the small tar distillery utilizes for this purpose those tar products on hand for which there is no other market, and the paint may be sometimes straight tar, tar and naphthalene, or tar, pitch, and oil mixed.

The usual intent in painting posts and poles is to retard decay. Hence the paint may be chiefly a preservative oil of tar, a high-boiling oil that will be readily absorbed by the wood, it may be chiefly a bituminous material plus a solvent that will leave a bituminous coat on drying, or it may be a combination of both. Many mixtures can be prepared for treating poles, but it seems enough to say that a paint similar to the heavy roof paint previously mentioned or a thin mixture consisting of tar and creosote oil in approximately equal proportions can be used. The mixture must be water free and should be applied to dry timber only.

SHINGLE STAIN.

A stain suitable for use on new structures where it is desirable to retain the new look of the shingles is commonly composed of either "straight" creosote oil or mixtures of creosote oil and varying amounts of linseed oil. Occasionally resins also are added. On account of the difference in price, the tendency is to use considerably more creosote than linseed oil. A large percentage of light volatile oil, or an oil containing appreciable amounts of naphthalene, should not be used. Stains are often ruined by the painter's desire to make them flow more easily from the brush, for which purpose he adds kerosene. The writer has tested a number of stains now on the market that are composed chiefly of light mineral oil and creosote with drier and linseed oil. While the mineral oil may help to prevent solidifying of the pigment at the bottom of the container, it has not the germicidal or wood-preserving properties of creosote. One large oil company interested in selling petroleum products suggests the following formula for a shingle stain:

Formula for a shingle stain.

	Gallons.
Light neutral oil, sp. gr. 0.857	2
Turpentine substitute, mineral naphtha	2
Boiled linseed oil	1
Coal-tar creosote, extra heavy	4
Good liquid drier	½
Total	9½

Color pigment, ground in oil, 1 to 2 pounds per gallon of stain.

In the writer's opinion this stain would be improved by substituting for the mineral naphtha, crude coal-tar naphtha or some of the first portion of the light oil distilling from tar. The preserving effect on the shingles is usually not given as much consideration as permanency of color; hence the selection of the best stain for a particular purpose will depend on the preference of the user.

ROOF CEMENT.

When prepared roofing is laid, some means of cementing the overlapping surfaces is required. Using melted pitch for this purpose is not considered here, for the reason that melting a small quantity of pitch and keeping it at the proper temperature are quite unhandy. It is preferable to use a cement that can be spread with a brush or trowel and will set as a firm waterproof film capable of withstanding the heat of the sun without melting. A material of this type may be prepared by " cutting back " a bituminous material, such as pitch, with a volatile solvent, benzol or light oil, for example, using as little of the solvent as possible. Roof cement is often prepared with the addition of other materials, such as sulphur or resins. Usually the cements " set " by the evaporation and absorption of the volatile constituent. The consistency desirable in the cement depends somewhat on the climatic conditions; therefore the proportions of bitumen and solvents must vary. The consistence should be such that the cement can be applied conveniently while warm and yet be heavy enough to hold the roofing surfaces in intimate contact. Roof cements are also used in repairing prepared roofs and prepared shingle roofs.

FLUME CEMENT.

In irrigation and mining districts where water flumes on trestles are common it is necessary to prevent excessive leakage of water in order to protect the foundations from being washed out. It sometimes happens that water is admitted to these flumes for definite intermittent periods between which the flumes are empty. Such conditions are ideal for warping and buckling the flume timbers and resultant leakage. A common remedy is the application of a protective coating to the inside of the flume. This coating should withstand atmospheric changes as well as the action of water.

One method of reducing leakage involves mopping or brushing molten pitch, or pitch preparations, on the inside walls and bottom of the flume, when it is dry. A so-called cement successfully used for this purpose consists of a medium soft pitch (coal-tar pitch) to which has been added, while it is liquid and hot, one-half to one per cent of sulphur. The sulphur, in powdered form, is added slowly while the mixture is continually stirred to keep it from boiling over.

Because of the need of conserving water, many flumes that are partly submerged in the ground have to be waterproofed. Similar coatings of pitch or pitch preparations are used for this purpose and the surfaces coated are usually " sanded " before the coating has set.

DISINFECTANTS AND INSECTICIDES.

Numerous antiseptics, insecticides, and disinfectants in common use are prepared with crude coal-tar products as their chief active ingredient. These preparations are used for widely different purposes, and include sheep dips, dog washes, cattle-car sprays, disinfectants for prisons, jails, hospitals, and household purposes, and disinfecting or antiseptic sprays for stables, barns, chicken houses, and street cars. In the manufacture of these preparations, consideration is given to the fact that the acid fractions, the middle-oil and creosote-oil fractions, have higher value as germicides than the other crude distillates from tar. The "straight" oil is ordinarily too concentrated to use alone, hence for this and other reasons many of these manufactured products are made in such a way that they are miscible with water in almost all proportions. Some form a clear solution and others a milky emulsion when diluted with water. The advantage of this form of preparation is that disinfectants or germicides of the different strengths required for different purposes may be prepared by merely diluting properly with water.

The preparation of these concentrated products usually involves the addition, in as small quantities as possible, of an emulsifying agent to the crude tar distillates having the highest germicidal value. In many of the ordinary disinfectants the fraction used is the oil, freed from naphthalene by chilling, that includes the crude carbolic-oil fraction and the creosote-oil fraction. Animal dips are made from the heavier fraction only, as the more poisonous carbolic acid is undesirable in such preparations. For hospital use, a product of higher grade frequently employed, is made from the refined creosote oil, or from "cresols" obtained from creosote oil. The ordinary product is made by mixing a rosin-soda soap with the tar oil in the following proportions:

Formula for a representative disinfectant.

	Pounds.
Rosin, common grade, yellow	95½
Caustic soda, commercial, 98 per cent	14½
Water (approximately 6 gallons)	49
Acid tar oil, 1.025 sp. gr. (approximately 33 gallons)	283
Total finished product (50 gallons)	442

METHODS OF MAKING DISINFECTANTS AND GERMICIDES.

Two different methods have been recommended for making these preparations. One consists of dissolving or melting the rosin in the hot oil and slowly adding, with constant stirring, the caustic soda previously dissolved in water. The other method consists in preparing a rosin-soda soap by warming the rosin with the caustic soda solution and finally adding the oil slowly and with constant stirring. It has been the author's experience in making these preparations that the latter method is preferable, as any excess water that may have to be added can be evaporated before adding the oil, thus eliminating the loss otherwise occasioned by evaporation and lessens the danger of boiling over. To prepare the product according to the formula given proceed as follows:

Melt the rosin in an iron kettle with closed steam, using a steam coil or a jacketed kettle, and meanwhile dissolve about half of the caustic soda in about three-fourths of the water. Add this solution slowly to the melted rosin, heating and stirring meanwhile. Dissolve the balance of the soda in the remaining water and add this in the same manner. The soapy mass looks milky at first, but the rosin soap that forms will have a smooth, dark, "livery" appearance. Heating hastens the reaction and evaporates the excess water, leaving the soap in proper condition for use. If the soda and rosin do not combine readily it may be necessary to add more water, boil, and then evaporate the extra water. To the hot boiling soap add the oil, small quantities at a time, stirring continually meanwhile. After about a third of the oil is added, turn off the steam, add the remaining oil and mix well. The finished product should be clear; in thin films, as those produced on the walls of a glass vessel when agitated, it should be amber red but transparent. Cloudiness usually indicates an excessive amount of water, which can be corrected by evaporation. When a small amount of the mixture is poured into water, a white milky emulsion should result without the deposit of oil at the bottom. The water content of the finished product is usually a little less than 10 per cent. In compliance with the insecticide act of 1910, it is necessary when making interstate shipments to state the percentage of inert ingredients (water in this case) as not exceeding a definite amount. The oils used should be freed from naphthalene, for the latter causes the oil to "fall heavy" and collect at the bottom of the vessel when mixed with water; it also causes "greasiness" when present in appreciable quantities.

DIPS AND WASHES.

When these preparations are made especially for animal dips or washes, the creosote fraction or a derivative therefrom is employed in place of the oil used in the above formula. The same method of preparation and similar proportions as above are used. The oil used generally contains 20 to 25 per cent of phenols other than carbolic acid. For further details on dips and directions for their dilution see bulletin 107 of the Bureau of Animal Industry.[16]

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[16] Chapin, Robert, Analysis of coal-tar creosote and cresylic acid sheep dips: U. S. Bureau of Animal Industry Bull. 107, 1908, 35 pp.

Washes of higher grade, for hospital use, are made in a slightly different manner. The rosin-soda soap is usually replaced by a vegetable-oil potash soap, and in place of the crude tar oils a refined product is used, which is a mixture of tar acids obtained from creosote, known as cresols. Glycerin is sometimes added. A well known, highly advertised product of this nature is composed of the following ingredients:

Composition of a wash for hospital use.

	Per cent.
Cresols	50
Potash soap	20
Water with a little glycerin	30
Total	100

The oils commonly used for making the potash soap are linseed oil, cottonseed oil, corn oil, or soy-bean oil, or mixtures of any of them. Linseed oil, however, saponifies more readily than the others and is more frequently used. To prepare such a solution proceed as follows:

Make a solution of caustic potash by dissolving 23 pounds of 98 per cent caustic in enough water to make 90 pounds, giving a solution with a gravity of approximately 24° B. Heat 100 pounds of raw linseed oil in a steam-jacketed kettle and when the oil is hot add the caustic a little at a time, continuing the application of heat. After about one-third or one-half of the caustic solution has been added, it may be necessary to add some cold water. Approximately 110 pounds of cold water will be required in all, but the caustic should all be added before more than one-half of the water is used. Instantaneous saponification or sudden heating and boiling over can be prevented by adding cold water when this tendency is observed. The yellow emulsion that first forms gradually changes to a clear, transparent amber-colored soft soap, which in mass looks dark. When saponification is complete and a sample of the product dissolves in water without oily particles rising to the surface, the oil or cresols may be added. The formula for the completed product thus prepared may be as follows:

Formula for a wash for hospital use.

	Pounds.
Raw linseed oil	100
24° B. caustic potash solution	90
Water	110
Cresols or acid-tar oils	250 to 300
Total	550 to 600

Considerable leeway exists for changing the relative proportions of soap and acids and for adding other substances.

The official U. S. P. product has the following formula:

Official formula for wash for hospital use.	Pounds.
Cresol	50
Linseed oil	30
Caustic potash (U. S. P.)	8
Alcohol	3
Water to make	100

and is prepared as set forth below:

Heat the linseed oil to 70° C. (158° F.). Dissolve the caustic potash in 5 pounds of water and heat to 70° C. Add this solution to the oil and mix thoroughly; then incorporate the alcohol and continue to heat without stirring until a small portion is found to be soluble in boiling water without the separation of oily drops. While the solution is still warm, add the cresol and mix thoroughly, maintaining the temperature at 70° C. Last, add water to make the total quantity weigh 100 pounds. Note that in this process the 8 pounds of caustic potash may be replaced by 5.4 pounds of caustic soda. In making calculations, it should be remembered that U. S. P. caustic potash is approximately 85 per cent pure caustic potash and that U. S. P. caustic soda is approximately 90 per cent pure caustic soda.

Preparations like the foregoing are often rated according to their ability, in dilute solution, to destroy certain germs or bacteria. Phenol is used as the standard, and preparations that are 1 to 10 times as strong as phenol are said to have a phenol coefficient of 1 to 10.

Other acids in tar distillates have higher phenol coefficients than cresol, although they are present in much smaller proportions. Different tars contain them in different proportions. Xylenol (dimethyl-phenol) is such an acid and is said to have a phenol coefficient of 10 to 12.

Many other preparations on the market have coal-tar products as an active ingredient. Naphthalene dissolved in benzine and turpentine or other solvent is used as a spray for protection from moths, and is also a common bedbug exterminator or repellant. Drip solutions and lavatory disinfectants are other minor preparations that are so prepared. Many powdered antiseptics and disinfectants are also prepared from tar products. Flake naphthalene is used for this purpose and may be mixed with varying amounts of other powdered materials which may be inert or active. Powdered slacked lime that has absorbed a considerable amount of tar oils or of crude carbolic acid finds use as an insecticide and fungicide.

WOOD-PRESERVING OILS.

In addition to the pure distillates of coal tar, wood-preserving oils for some purposes are made by mixing coal tar with the heavy coal-tar distillates. The content of tar permissible in the mixture depends upon the specifications of purchase. Not uncommonly a preservative is required with a specific gravity of 1.06 to 1.12, a free-carbon limit of 2 per cent, and a residue, on distillation in a retort to 355° C., of not more than 40 per cent. It is evident that the maximum amount of tar that can be added here depends entirely on the specific gravity, the carbon content, and distillation residues of both the oil and the tar, as is clearly shown in the example below:

Example of a tar and oil mixture.

	Assumed properties.		Mixture[a] of 1 part tar and 3 parts oil.
	Coal tar.	Tar oil.	
Specific gravity	1.18	1.04	1.075
Free carbon ... per cent	6	.0	1.5
Residue over 355° C ... do	70	10	[b] 25 to 30

[a] Parts by volume.

[b] Approximately.

This mixture fills the requirements of the specification, whereas neither the tar nor the creosote oil alone would pass.

As tars of low specific gravity usually contain the least free carbon, it follows that they can be used in greater proportions in tar-creosote mixtures to meet specifications such as those mentioned. It will be noted that a tar containing 20 per cent free carbon can not be used in proportions larger than 10 per cent of the total mixture and pass the specification cited above.

The use of tar in wood-preserving oils is in one sense an adulteration, but gives the oil certain desirable properties.

The presence of the bitumen of tar increases the waterproofing qualities as well as the proportion of high boiling constituents. The latter retard evaporation of the preserving oil, do not evaporate, and are desirable for other minor reasons in wood preservers for some purposes. Incidentally, this use of tar increases the possible output of wood preserver from a plant and the total available supply; also it decreases the average cost per gallon. To make possible the utilization of the maximum percentage of tar in these mixtures, the tar is sometimes filtered and centrifuged to reduce the percentage of free carbon as much as possible.

PRODUCTS OBTAINED BY FURTHER REFINING THE CRUDE DISTILLATES.

Highly refined coal-tar and chemical products are not prepared in the tar distillery, but are usually manufactured in a separate plant from the cruder materials supplied by the tar works. However, some of the larger distilling plants prepare crude and refined benzols, cresols, and naphthalene. War conditions brought about changes in the operation of tar works, some crude chemical products being made by plants that under ordinary conditions had no inducement to consider manufacture. Products whose manufacture is briefly considered here are as follows: Crude and refined benzol, solvent naphtha, crude and refined toluol, xylol, crude and refined carbolic acid and cresol, crude and refined naphthalene, and crude and refined anthracene.

BENZOL AND SOLVENT NAPHTHA.

Crude naphtha, the first distillation fraction from tar, contains benzol, toluol, and other hydrocarbon oils. The initial step in refining naphtha is washing with dilute (12 per cent) sulphuric acid by agitation. Then the naphtha is allowed to settle, separated from the acid, washed with water, and finally washed with dilute (about 6 per cent) caustic-soda solution. These washings remove a small percentage of the original volume and include substances known as "bases" and "phenols." The purified oil is redistilled with closed steam in special stills. In some stills live steam is also used. The method of distillation or fractionation employed depends on the product desired, whether 90 per cent benzol, 50 per cent benzol, or another similar product. The fact that the various constituents of crude naphtha have different boiling points is utilized in separating by distillation. Table 8 showing 90 per cent benzol signifies that product from naphtha which on distillation will yield 90 per cent distillate at 100° C. Accordingly, 50 per cent benzol may contain a considerably larger proportion of higher boiling oils, such as toluene and xylene. Sometimes, particularly when an especially pure or high-grade benzol is desired, a double distillation is made.

TABLE 8.—*Some properties of the light oils from coal tar.*[a]

Oil.	Color.	Distillation.	Specific gravity at 60° F.	Wash test, not darker than—	Flash point (A. S. T. M. closed tester method).
Pure benzol[b]	Water white.	100 per cent within 2° C.	0.875 to 0.885	No. 4.	Below freezing.
100 per cent benzol.	do.	100 per cent at approximately and not above 100° C.	.875 to .885	No. 6.	Do.
90 per cent benzol.	do.	Approximately and at least 90 per cent at 100° C.	.870 to .882	No. 6.	Do.
50 per cent benzol.	do.	Approximately and at least 50 per cent at 100° C. Approximately and at least 90 per cent at 120° C.	.868 to .880	No. 6.	About 23° F.
Motor benzol	do.	Between 79.5 and 135° C. Approximately 85 per cent at 100° C.	.870 to .882	No. 6.	

[a] As published by The Barrett Co. in its pamphlet "Refined coal-tar products."
[b] Pure benzol should crystallize at approximately 5° C.

TABLE 8.—*Some properties of the light oils from coal tar*—Continued.

Oil.	Color.	Distillation.	Specific gravity at 60° F.	Wash test, not darker than—	Flash point (A. S. T. M. closed tester method).
Straw-color benzol.	Straw........	At least 80 per cent at 100° C.....	.862 to .882	None.	....
Pure toluol.....	Water white.	100 per cent within 2° C...........	.864 to .874	No. 4..	+7° F.
Commercial toluol.	....do........	Not over 5 per cent at 100° C..... Approximately and at least 90 per cent at 120° C..............	.864 to .874	No. 6..	About +15° F.
Straw-color toluol.	Straw........	At least 80 per cent at 120° C.....	.862 to .872	None.	About +17° F.
Pure xylol......	Water white.	100 per cent between 137 and 142° C.	.860 to .870	No. 6..	About 82°
Solvent naphtha.	....do........	Not over 5 per cent at 130° C..... Approximately and at least 90 per cent at 160° C.	.862 to .872	No. 14[c]	About 80° F.
Crude solvent naphtha.	Dark straw ..	At least 80 per cent at 160° C.....	.862 to .882	None.	Do.
Hi-flash naphtha.	Water white.	100 per cent between 150 and 200° C.	.870 to .880	No. 9[d].	Not below 100° F.
Crude heavy solvent naphtha.	Amber to red.	Not over 10 per cent at 160° C.... At least 90 per cent at 200° C.....	.940 to .966	None.	Not below 90° F.
Heavy naphtha.	Deep amber to dark red.	Not over 10 per cent at 160° C.... About 70 per cent at 200° C.......	.925 to .950	None.	About 115° F.

[c] 66 acid 5 minutes.
[d] 60 acid 5 minutes.

One method of working up the washed crude naphtha is by distilling it with closed steam, thereby separating two fractions—crude benzol and crude solvent naphtha—and a heavy residue. Open steam is sometimes used during the latter part of the distillation. The crude benzol is collected until a sample of the distillate from the condenser, on distillation in a laboratory retort, shows the first drop at 110° C. The second fraction—"crude solvent"—is now collected until the oil coming from the condenser has a specific gravity of approximately 0.968 at 60° F. The residue is worked up with heavier distillates. The crude benzol is then washed with one-half to 1 per cent of its volume of concentrated sulphuric acid and subsequently with water, with dilute caustic soda solution, and finally with water again. This washed product is rectified and the products collected are 90 per cent benzol and 50 to 90 per cent benzols. By a second rectification of the 90 per cent benzol, a pure product—pure benzol—is obtained.

The crude solvent naphtha is washed similarly with acid, water, and alkali and is rectified into a fraction known as 90 per cent at 160° C. However, various solvent naphthas are prepared according to their intended uses. Moreover, by further rectification solvent naphtha yields a number of products as, for example, toluol and xylol. The residue from the last benzol rectification is added to the crude solvent naphtha and the residue from the further distillation of this fraction is utilized with higher boiling fractions.

Chemically pure benzol, known also as benzene, is a definite chemical compound, and is quite different from the petroleum product known as benzine. It boils at 80° C. and "freezes"—solidifies to a mass of crystals—at approximately 5° C. Its specific gravity is 0.885 at 60° F. This product is of great importance commercially, as it is the source from which aniline and many dyes, as well as other chemical products, are made. Synthetic carbolic acid is also prepared from benzol. Pure benzol is not used as a motor fuel, although mixtures containing it with toluol, solvent naphtha, and gasoline are particularly suitable for this purpose. A large gas company producing quantities of this oil recommends as motor fuel a mixture containing:

Recommended composition of a motor fuel.

	Per cent by volume.
Toluol	50
Benzol	40
Solvent naphtha	10
Total	100

The benzol, toluol, and solvent naphtha are obtained from city gas by absorption—stripping—and not from coal tar.

Benzol and gasoline mixtures containing 50 to 70 per cent of benzol make satisfactory motor fuel. Toluol may also be used successfully if added to such a mixture. On starting a motor in cold weather, less difficulty is experienced from these mixtures than from the formula recommended above.

More energy is stored in such a motor fuel than in an equal volume of ordinary gasoline, the relative values being approximately as follows:

Heating value of gasoline and benzol.

	Heat of combustion per pound of combustible, B. t. u.	Heat of combustion per gallon of combustible, B. t. u.
Gasoline	20.000	122,800
Pure benzol	18,054	133,100

It is claimed that use of such a fuel in an automobile will give 25 per cent more mileage.

Benzol is preeminently a solvent; it dissolves soap and many other substances containing water. It is invaluable in the manufacture of paint, for its use in small quantities in mixed paints prevents "livering" or saponification due to alkaline tendencies of the paint. It is used in paint for priming and is said to give a firmer bond between the paint film and the wood. The varnish and the rubber industry also make extensive use of the solvent properties of benzol.

The uses of benzol and of products obtained from it can be shown as follows:

Use of benzol.

Benzol	Aniline	Dyes of various colors.
	Synthetic carbolic acid	Explosives. Drugs. Antiseptics. Dyes.
		Motor fuel.
		Solvents, in paint, oil and rubber industry.
		Cleaning solutions.
	Miscellaneous chemical products	Flavoring and perfume materials.

Solvent naphtha is used as a solvent much the same as the benzols. Because of differing in flash point and boiling point solvent naphtha is preferable to benzol for many of the uses to which the latter is put. It is also used in the refining of anthracene and in other chemical washing processes.

TOLUOL.

Pure toluol (also known as toluene) is a colorless oily liquid with an odor somewhat like that of benzol. Its freezing temperature is low, nearly—100° C. Its boiling point is 111° C. and its specific gravity is 0.872 at 60° F. Its chemical properties are in many respects like those of benzol.

Commercial toluol, a product of which 90 per cent will distill below 120° C., is usually obtained from crude benzol. The crude benzol distilled between approximately 100° and 120° C. is termed commercial toluol and has a specific gravity of 0.862 to 0.870 at 60° F. The uses of this product are similar to those of the benzols. Having a higher boiling point it is less volatile and dries more slowly when used in varnishes and similar preparations—an advantage in many of these preparations. It is a valuable ingredient in turpentine substitutes.

Commercially pure toluol may be prepared from the 90 per cent toluol by further distillation and rectification. As the boiling point of pure toluene is 111° C., the fraction separated begins to boil at 111° C. and to yield 95 per cent at about 111.8° C. or 100 per cent within 2° of the boiling point of toluene, that is, 111° C.

Chemical plants work this product into a more refined product. Commercial toluol is the source of the explosive T.N.T. (trinitrotoluene), of dyes for cotton, of synthetic flavoring, and perfume materials, and of other chemical compounds.

XYLOL.

Xylol is another commercial product from the light fraction of coal tar. It has a higher boiling point than benzol or toluol and is recovered from the distillate residues from the preparation of pure benzol and pure toluol. Pure xylene exists in a number of slightly different forms having boiling points ranging from 137.5° to 142.6° C. Its refining is like that of benzol and toluol. A fraction is collected a large percentage of which will distill within close temperature limits, approximately 136° and 140.5° C., the limits varying according to the specifications of purchase. The crude product is a water-white to pale yellow oil with a specific gravity of 0.865 to 0.87+; the specific gravity of purified xylol is 0.87.

Xylol is a satisfactory solvent and, as its high boiling point indicates, does not volatilize rapidly in the air at atmospheric temperatures. Therefore, it is used for purposes requiring the use of products that volatilize slowly. Pure xylol is the source of a number of synthetic chemical compounds.

Weiss estimated that in 1911 the coal-tar solvents used in the United States were apportioned as follows:

Uses of coal-tar solvents in 1911.

	Per cent.
Paint and varnish industry	47
Rubber and rubber cement	18
Imitation-leather industry	10
Chemical manufacturers	11
Miscellaneous	14
Total (2,000,000 gallons)	100

These figures do not represent the present distribution of coal-tar solvents. The World War with the development of the gas-stripping process and recovery of toluol and benzol, the increased use of explosives, the development of the chemical industries, and the use of benzol and toluol in motor fuels have altered conditions which are not stable at the present time.

CARBOLIC ACID.

The middle-oil fraction obtained by distilling tar is the oil " worked " for carbolic acid. Acid portions obtained in refining the lighter fractions are combined with this fraction and refined. Pure acid usually is not prepared at the tar works, but at a special chemical plant, and smaller tar works do not even undertake to produce crude carbolic acid. In some parts of the country the writer has found crude carbolic oil being sold under the name " crude carbolic acid." The crude oil as it comes from the still contains about 20 to 40 per cent naphthalene and 15 to 35 per cent of tar acids, which include cresols and carbolic acid. There is 5 to 12 per cent of carbolic acid in this oil. The percentage of tar acids in tars is shown in Table 2, page 9.

The method of "working up" the acid distillates from tar depends on the character of products sought, which may be a single product like crude acid containing phenol and cresols, or a number of products such as crystallized carbolic acid, crude carbolic acid, and refined cresol. The general process of manufacture is much the same, but the washing methods, strengths of washing solutions, and distillation fractions separated are of course dissimilar. Details of the process can not be described here, but only the basic principles of refining considered.

The separation of two or more allied substances depends on differences in their properties. Phenol and cresols have much the same chemical properties, and their separation from the nonacid bodies is based on their solubility in dilute caustic soda solution, which yields concentrated acid when the soda is neutralized with sulphuric acid or its equivalent. They actually combine chemically with the soda solution forming carbolates and cresolates. The separation of the tar acids is based on a difference in boiling point. Pure phenol boils at 182.6° C., but cresol has a much higher boiling point, 192° to 202° C. Cresol exists in three modified forms known as three distinct cresols, with boiling points 192° to 202° C. As used here, the word "cresol" means a mixture of the three in any proportions.

When only a crude acid, one that contains the cresols and phenol, is desired, the middle oil and the acids recovered from the light oil or with the last portion of the light oil distilled are given fewer washings and distillations than in preparing the purer product, and stronger caustic-soda solution is used.

When pure refined phenol is sought the first washings are made with weaker soda solutions and the subsequent washings with stronger solutions. The weaker solutions yield the highest grade of phenol.

Crude cresylic acids are prepared from the residue acid in the separation of phenol. Pure cresol is prepared from the crude product by distillation and fractionation. Commercially the name "carbolic acid" is not applied to phenol alone; it is sometimes given to crude tar acids containing cresols mixed with high or low percentages of phenol. Crude carbolic acid was recognized in the United States Pharmacopœia, 1890 edition, as consisting of 90 per cent tar acids.

Briefly, middle oil may be refined as follows: Chill the oil and drain the liquid portion from the naphthalene. Redistill in a similar manner as tar is distilled, using a still with a dephlegmating head.

The fraction collected between 165° and 200° C. is termed "carbolic-acid oil" and is treated further for the acid. It has a specific gravity of 1.0 to 1.005 and contains considerable naphthalene. The fractions obtained may be, approximately:

Fractions from middle oil.

	Per cent.
Up to 150° or 165° C., when no more water comes over (used as crude benzol)	1 to 4
165° to 200° C. (carbolic-acid oil)	18 to 22
200° to 220° C. (naphthalene oil)	25 to 45
Residue (and loss 1 to 2 per cent)	56 to 29

The naphthalene oil is chilled and centrifuged; containing 25 to 30 per cent of tar acids (mostly cresols) and is sold as "crude commercial carbolic acid." The residue may be used in preserving oils, creosote and similar crude products. The carbolic-acid oil fraction collected between 165° and 200° C. is separated from naphthalene, then washed or agitated with a warm solution of caustic soda, which unites with the acid to form a water-soluble compound. After it settles this compound of carbolic acid and soda—sodium phenolate—is separated from the remaining oil, treated in the same manner as before with the proper amount of sulphuric acid, and evaporated to the proper concentration. The tar acids liberated are separated after settling as "crude carbolic acid," which is distilled. The fractions collected are as follows:

Fractions from crude carbolic acid.

Up to 180° C.	Chiefly water.
180° to 200° or 205° C.	Main carbolic acid fraction.
205° to 220° C.	Chiefly cresols.

The range of crystallization of carbolic acid is from the 180° to the 205° C. fraction. The carbolic acid is not absolute phenol yet, being contaminated with some cresol. Further fractionation of the crystallizable portion—closer to 182.6°, the boiling point of phenol—yields pure carbolic acid. The mother liquor draining from the crystallized acid in the crystallization tanks is chiefly cresol and is used in making various disinfectants and antiseptic washes and in preparing pure cresol.

Pure phenol (U. S. P.) contains not less than 97 per cent phenol; it occurs in colorless needle-shaped crystals or as a white, occasionally reddish, crystalline mass; it has a characteristic, somewhat aromatic odor. An aqueous solution (1 to 15) is clear. Phenol melts when gently heated, the congealing point being not below 38° C. and liquifies on the addition of about 8 per cent water. Ten grams heated on a water bath volatilizes without leaving more than 0.05 gram residue. The vapors are inflammable.

The alkaline—caustic soda—washings of the lighter tar distillates contain, when refined, considerable proportions of tar acids; these are usually added to the crude product from the middle oil and refined. The presence of these acids, particularly in light oil, is to be expected when the latter fraction is collected between 170° and 210° C.

A commercial crude cresylic acid is prepared during the manufacture of refined carbolic acid or phenol. The fractions, which have a higher boiling point than desired in the phenol fraction, obtained from redistillation in the recovery of phenol, are rich in cresols and are further refined for a purer product. Different qualities of mixed cresols are on the market and almost any grade can be purchased on specification. Some of the commonly marketed products are: Cresylic acid, 50 per cent; cresylic acid, 95 to 97 per cent, dark; cresylic acid, 97 to 99 per cent, straw color; and cresol, U. S. P.

Cresylic acid is a name commonly applied to the different tar acids, chiefly or entirely cresols, that boil above 185° C. The lower grades, however, often contain appreciable amounts of phenol. The United States Pharmacopœia defines "cresol" as a mixture of isomeric cresols obtained from coal tar. Its specific gravity is 1.03 to 1.038 at 25° C. Not less than 90 per cent by volume distills between 195° and 205° C. It is a colorless or yellowish to brown yellow, highly refractive liquid, becoming darker or assuming a reddish tint with age and on exposure to light, and having a phenol-like, sometimes empyreumatic, odor.

In preparing cresol the acid is air blown in order to remove some of the sulphur compounds and other impurities that impart a disagreeable odor.

The various tar acids described are used in the preparation of numerous germicides and antiseptics, in the manufacture of other chemical products, in soaps and soap preparations, and in numerous other specialties.

NAPHTHALENE.

The solids crystallizing from the crude distillates of coal tar and from some of the distillates obtained during the rectification of benzol, naphtha, and tar acids are chiefly naphthalene and naphthalene compounds. These solids are freed from oil as far as possible by settling, chilling, and draining. The solids remaining are pressed in a hydraulic or similar press to extract the oil which they still retain. The name "crude naphthalene" is applied to the solid material that has been separated from oil by chilling and draining and sometimes is applied to the product from the press.

A purer product is obtained by hot pressing, which consists in pressing molded cakes of the crude naphthalene in a press having its plates heated, usually with steam. The naphthalene obtained is fairly satisfactory but is not absolutely pure. It is not snow white but pinkish, in which form it has many uses. Pure naphthalene is obtained by refining.

Commercially pure solid naphthalene is prepared as follows: The cakes from the hot press are broken up and washed with a hot caustic-soda solution in a closed tank or kettle provided with an agitator and a steam connection for heating. The naphthalene is here fused and freed from the tar acids which combine with the caustic soda. The wash solution is drained off and the residue in the kettle is given a hot wash, which is followed by a washing of strong sulphuric acid, several washings with water, and a wash with a weak solution of caustic soda, which is followed by a water wash. This washed hot naphthalene, now liquid, is distilled in the same way as middle oil. The fraction coming over above 210° C.—usually up to 225° or 230° C.—may be molded directly as solid naphthalene.

Flake naphthalene is prepared by subliming the cake from the hot press or sometimes that from the cold press. In addition, the product obtained by centrifuging the solids from the crude distillates is sometimes used. A fine grade is obtained by subliming the wash product from the hot press as prepared for distillation.

Sublimation is a simple process, the naphthalene being heated in shallow pans by a steam coil or other suitable means and the vapors being condensed in a large special chamber or room (see fig. 10). The naphthalene thus condensed forms a deposit on the walls, ceiling, and floor of fluffy white flakes, which have a characteristic penetrating odor and are insoluble in water. Naphthalene is soluble in ether, alcohol, benzene, toluene, and the essential oils.

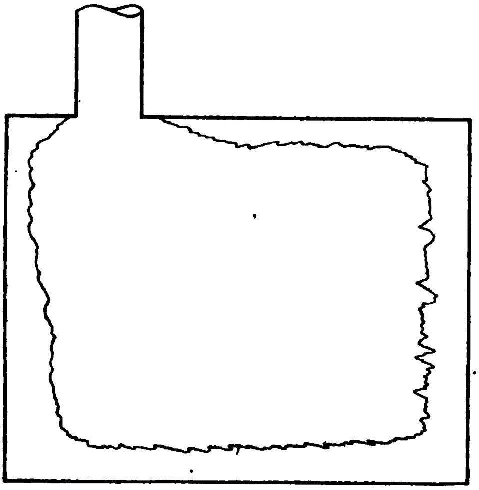


FIGURE 10.—Naphthalene chamber, showing flake naphtha condensed on walls, ceiling, and floor.

ANTHRACENE.

Anthracene is not usually produced in small tar works except as it exists in the anthracene-oil fraction obtained in distilling tar. In such plants it is common practice to include this fraction with the creosote fraction, thereby enhancing the value of the latter as a wood preservative.

The crude product is obtained by cooling the anthracene-oil fraction and allowing the solids to separate and the oil to drain off. After the oil is drained from the solids, the latter are bagged and pressed or "whizzed" (centrifuged) to expel the oil still retained with the solids. This crude anthracene is usually sold as such. It amounts to about 5 or 10 per cent of the total distillate fraction from which it was obtained and contains approximately 15 to 35 per cent of anthracene. Different tars yield different amounts of anthracene. To purify the crude product further, it is either ground and agitated with hot solvent naphtha and drained, or is washed in a whizzing process with solvent naphtha. The dried product made in either way contains approximately 70 to 80 per cent of anthracene.

A high-grade commercial anthracene is sometimes prepared by redistilling the crude anthracene oil obtained in the distillation of tar and separating a fraction that includes the distillate with a specific gravity higher than 1.07 at 60° F., the change or "cut" being made when the distillate coming over has a specific gravity of approximately 1.25 to 1.30 at 60° F. This fraction is cooled, drained of oil, pressed and washed, and sometimes sublimed. The sublimation process is like that employed for purifying naphthalene except that the inclosed anthracene pans are heated by direct fire and superheated steam is blown directly on the melted anthracene and a water spray is used to condense the product. The commercial grade of anthracene is known as 80 per cent anthracene. Its further treatment is left to the alizarin works or other chemical plants.

SPECIFICATIONS.

The necessity for the various, and, in many cases, widely different specifications for certain tar products is evident from the many varieties of tar, all giving more or less similar products on distillation, and from the many ways in which these tars are distilled, fractionated, refined, and mixed. When a complex product of tar is required and its most desirable and least desirable components are known, it is natural for the consumer to include in his specification the maximum amount of the desirable ingredient that the manufacturer can produce and to exclude excessive amounts of the undesirable. These limiting figures have been a benefit to the tar industry rather than a hindrance, since they have developed research into further uses and have increased our knowledge of the properties of these products.

Specifications are drawn up for definite purposes and have definite meanings, some of which are not always evident to the casual reader. For example, a particular timber preservative may be defined as containing a definite minimum amount of matter insoluble in solvents such as hot benzol. This is in fact a way of limiting the proportion of free carbon that will be tolerated in the required product, free carbon being the only likely ingredient insoluble in hot benzol, and shows the tar distiller at once how much tar, if any, can be added to pure creosote oil and still have the product comply with the specifications. The full meaning of a specification can be appreciated and understood only by knowledge of the properties and uses of the various products and their ingredients.

Although specifications, with their frequent revisions, are becoming more definite and restrictive, thus limiting the use of the individual ingredients, the efforts of the tar distiller to produce the maximum possible amount of some products tend to neutralize the ill effects of restrictions. An example is the increased percentage of coal tar permissible in some wood-preserving oils as the distiller has used filtering or centrifuging to remove the objectionable free carbon. When the only limiting factor regulating the addition of tar is that the oil must contain, for example, not more than 2 per cent of free carbon, it is evident that such oil could not contain more than 10 per cent of a tar containing 20 per cent of free carbon. If the tar is filtered while hot and its free carbon content reduced to 6 per cent, not more than 33 per cent of it can be used.

The manufacturer of creosote desires to limit the use of coal tar, primarily because he knows the difficulty in obtaining the required penetration and saturation when much is present; and realizes that the free carbon in the tar is largely the cause. The tar distiller, in eliminating free carbon, not only makes possible the use of a larger proportion of tar but does so in a way that makes it impossible to determine from the per cent of free carbon in the finished product what percentage of tar is present. If it is desirable for other reasons to limit the percentage of tar allowable, additional regulations are imposed, such as limiting the amount, the physical properties, and maximum specific gravity of the residue remaining above defined temperatures on distillation. With other products as well, adulteration is prevented and purity obtained by specificying boiling points, specific gravity, solubility, volume of fractions at given temperatures that are obtainable on distillation, color, odor, and viscosity.

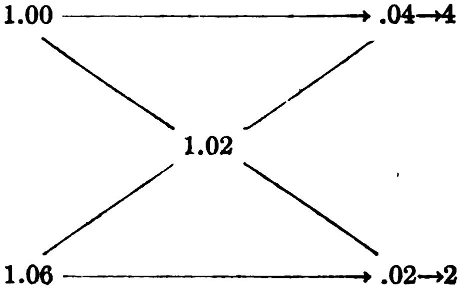
To manufacture tar products that comply with some specifications is not difficult, but occasionally a specification compels the distiller to use his utmost skill to produce the grade or quality specified.

SPECIFIC GRAVITY.

One of the simplest methods of designating certain crude tar distillates is by defining the specific gravity of the fraction required. Under the circumstances, it is only necessary for the still operators to separate a fraction with the specific gravity named. If it is desirable to make more than a normal output of this product it is only necessary to add to the separated fraction a quantity of the fractions with a lower and a higher specific gravity. For example, if a crude distillate having a specific gravity of 1.02 is required, the supply can obviously be increased by adding properly mixed distillates such as the following:

Sp. gr. of distillate 1.	Sp. gr. of distillate 2.	Volumes of distillates 1 and 2, respectively, which have a sp. gr. of 1.02 when mixed.
1.06	1.00	1 to 2
1.06	1.01	1 to 5
1.05	1.00	2 to 3
1.05	1.01	1 to 3
1.04	1.00	1 to 1
1.04	1.01	1 to 2
1.03	1.00	2 to 1
1.03	1.01	1 to 1

For quickly determining the specific gravity of an oil produced by mixing definite volumes of two oils of known specific gravities the following diagram may be of assistance:



The numbers at the left, above and below, represent the specific gravity of the oils to be mixed. The number in the center is the desired specific gravity of the mixture. The differences between the desired specific gravity and that of the oils to be mixed are expressed by the numbers at the right, which are printed diagonally opposite the specific gravity of the respective oils. The large arrows point to the relative amounts by volume of each oil required to produce the desired mixture.

This amount multiplied by 100, designated by small arrows, gives in whole numbers the relative amounts of the oils that when mixed will have the desired specific gravity. Thus, in the example it can be seen that 2 and 4 parts by volume of oils having specific gravities of 1.06 and 1.00, respectively, will produce, when mixed, an oil having the specific gravity 1.02.

BOILING OR MELTING POINT.

Another simple specification is exemplified by designating an oil by its boiling point or melting point. In general, the lighter oils have a lower boiling point than the heavier ones and the lighter constituents must be removed by distillation or otherwise until the product has the desired boiling point. Mixing some of the low-boiling fractions with varying proportions of a much higher boiling fraction yields a product with an intermediate boiling point.

The melting point commonly used in specifications for such substances as pitch and pitch products is another way of expressing the consistence of a pitch. The more oil distilled from them the harder they are and, correspondingly, the higher is the melting point. When the melting point is too high to pass the specifications, it is common practice to add enough liquid, or lower boiling, fractions to lower the melting point to the desired limit. Naphthalene, creosote oil, anthracene oil, or residue oils from the refining stills may be used. Anthracine oil or creosote oil is preferable, and napththalene is not to be recommended.

Specifications for some of the refined products from tar also have a clause covering the melting point.

As every pure chemical product has a definite melting point, the purity of commercial products can, to a certain degree, be estimated from such tests. The failure of a finished product to comply with melting-point requirements usually means that additional refining is necessary. Sometimes a specification calls for a product that when distilled to a given temperature will have a certain minimum or maximum amount of residue with definite characteristics. Thus, 90 per cent benzol has a residue of less than 10 per cent at 100° C., motor fuel must distill to dryness at about 200° C., and a wood-preserving oil must have a residue not greater than 40 per cent at 355° C., and the residue must not be brittle. To comply with such specifications it is necessary in distilling to so collect the various fractions that a preponderance of the undesirable high-boiling or low-boiling substances is not present in the finished product. For example, should the residue of the wood-preserving oil be greater than 40 per cent at 355° C., it is necessary to add enough oil that will distill below 355° C. to the product to reduce the residue to the desired amount on distillation. Brittleness of the residue usually indicates a high percentage of free carbon, which may be decreased by reducing the percentage of tar in the mixture or by using a "low carbon" tar.

FLASH POINT.

The "flash point," that is the lowest temperature at which the vapors arising from an oil will ignite from a small flame and go out without igniting the oil, is used in specifications to control the proportion of low-boiling combustible ingredients. The distiller who is acquainted with the flash point of the numerous distillation fractions can control this factor by making "cuts" at the proper time.

In general, the flash point is lowered as the per cent of low-boiling oils in a given mixture is increased, and vice versa. The flash-point test of a dip paint to be used warm is of value in determining whether or not the paint may be safely used indoors; the test is also of great value in specifications for motor fuel, creosote preservative, solvent oils, pitch preparations, and similar products.

When a product with a certain fluidity at a stated temperature is desired, a viscosity stipulation is inserted in the contract. In general, distillates of low specific gravity are more fluid than distillates of high specific gravity, although this is not universally true as the temperature and other factors affect fluidity.

MEETING SPECIFICATIONS.

When a number of limiting factors are included in a single specification, it is sometimes more difficult to make the adjustments or changes that will give the material the specified properties. A change in the proportions of the ingredients in a mixture will probably change more than one of the properties of the mixture. The writer can not give a method of manufacture that will apply to the specifications covering all tar products, but can show by example some of the considerations involved in manufacturing products to comply with specifications.

Assume that a bituminous concrete tar is required to meet the following specifications:

1. Shall not foam at	° C.	150
2. Specific gravity at 25° C. (77° F.)		1.20 to 1.30
3. Bitumen soluble in carbon bisulphide, not less than	per cent	85
4. Distillation yield to 170° C	do	0.0
Distillation yield 0° to 270° C., not more than	do	10
Distillation yield 0° to 315° C., not more than	do	20
5. Distillate, total specific gravity at 25° C		1.03
6. Distillation residue—melting point, cube method, not more than	° C.	75

Here the product required is evidently a soft pitch, as the residue from distilling off less than 20 per cent at 315° C. has the melting point of a hard pitch. The specific gravity of the distillate, according to item 5, is 1.03, and it comes over above 170° C., hence one may conclude that no light oils are present in appreciable amounts and that the product is, perhaps, a tar that has been distilled to about 200° C. That it is free from water is shown by its not foaming at 150° C. An average coal tar distilled to about 200° C. would have a specific gravity within the limits prescribed, although for some tars it might be below the lower limit. The maximum amount of free carbon allowed is 15 per cent, as at least 85 per cent of the product is soluble in carbon bisulphide. Accordingly, one may estimate that the original tar contained 12 per cent of free carbon, for about 20 per cent of the original tar has been removed as light oils in preparing this product.

In "working up" a tar for the first time into a product of this nature, it is well first to distill a sample on a laboratory scale, often saving considerable work thereby, for after a product is prepared and is found to be lacking in some qualities, further treatment is not always easy.

In preparing this road tar, it is essential that the original tar contain less than 12 per cent free carbon or that it, or part of it, should have some of the free carbon removed. When free from water the product will not foam at 150° C. The finished product can easily be made to have a specific gravity within the limits given by "cutting back" pitch with heavy oils. No minimum limits of the yield on distillation are set, therefore there is considerable leeway for the manufacturer in adding the oils that will give the required specific gravity. Should the fractions coming over on distillation be greater than prescribed, the addition of harder pitch, which contains practically no oils distilling at the temperatures given, will remedy the defect. Under normal conditions the total distillate will have a specific gravity of 1.03, but should it be too low, the addition of high-boiling oils such as creosote will remedy this defect. When honestly prepared, a product that complies with the first five requirements will usually comply with the sixth as well. However, when an attempt is made to "cut back" a very hard pitch with a little middle oil or light oil, the distillation will probably yield a residue with a melting point above the limit of 75° C.

An additional requirement is sometimes added in specifications for such a material, namely, viscosity. In general, there is no difficulty in obtaining a product with the viscosity usually specified, for small additions of oil make the product more fluid. The oil used depends on the quantity distilling at the temperatures named, 270° and 315° C. Some manufacturers have used naphthalene to control viscosity. A small amount of naphthalene will materially alter the viscosity of a pitch of a given melting point, but the addition of naphthalene in appreciable proportions is not to be recommended.

REQUIREMENTS FOR SPECIAL OILS.

In specifications for creosote oil or for wood-preserving oils a number of requirements are included, all of which help the manufacturer to understand what fraction or fractions are wanted. The stated requirements for specific gravity and distillation range show how the distillates from tar must be separated at the still. The maximum amount of light oils that is allowable can also be estimated roughly. The free carbon and the residue requirements show clearly how much tar may be added; the specific gravity also limits the proportion of tar. The percentage of tar acids required and allowed designates whether or not an oil that has had the acids removed can be used and whether crude acids can be included as a considerable part of the oil. The acids normally present in the high-boiling distillates are usually desirable in the proportions as found, but the presence of an undue amount of phenol is said to have a deleterious effect on the wood treated. The amount of naphthalene permissible is sometimes limited to prevent the wholesale "dumping" of this product, which is sometimes unsalable, into the oil, where a large proportion of it is undesirable. Adulteration with mineral oils is guarded against by specifying the minimum specific gravity of the fractions obtained on distilling a sample, by the amount of matter unsaponifiable by sulphuric acid and caustic soda, and by the odor during distillation.

One specification previously mentioned requires an oil that is a pure distillate from coal tar, with a specific gravity of 1.08 to 1.12 at 25° C. and not more than 1 per cent of matter insoluble in hot benzol and chloroform. Regardless of any other requirements, it is evident that when tar is distilled as described to produce a medium pitch a very small fraction is obtained with a specific gravity above 1.08. Apparently, either anthracene oil or a mixture of this oil with the last creosote coming over during the distillation of tar is desired; to produce a small amount of this, a large amount of tar must be distilled. The endeavor to increase the production of this oil has led some manufacturers to add to creosote oil an appreciable percentage of tar containing practically no free carbon; thus the specifications are complied with fully except the requirement that "the oil shall be a pure distillate of coal tar." Strict requirement may be accomplished honestly and the production increased by distilling the tar to a very hard pitch or carbonizing it. The price obtained for the oil and for the resulting hard pitch or coke is one of the controlling factors that determine how best to prepare these oils.

Some specifications stipulate products that are practically impossible to prepare. Such specifications usually are drawn up by inexperienced men and can be altered. An example is the specification of a low-gravity oil with only high-boiling fractions and a large residue over 355° C. and vice versa. Again, the quantity of distillate obtained at different temperatures may not be compatible with other specified requirements. As a rule their incongruities are quickly recognized when the properties of the tar employed to manufacture the specified products are understood.

CARBONIZATION OF COAL TAR—DISTILLATION TO COKE.

When coal tar is distilled to a soft pitch, the volume of pitch produced is approximately twice that of the oil distillates. Coke-oven tars and vertical retort tars do not yield so high a percentage on distillation. As there is a greater demand for the oil than for the pitch, it is desirable to increase the percentage of oil, simultaneously reducing the quality of the pitch. In some plants this is being accomplished by making a very hard pitch which is subsequently powdered and used as fuel; the yield of oil is thus increased from 32 per cent of the tar to 50 per cent of it.

By distilling at a red heat to a solid residue, coke yield of oil is still higher, and the coke is a correspondingly smaller percentage of the original tar. In making such a distillation—that is, coking the tar—the author's results in a small 6-ton still checked very closely those in the laboratory. The following table shows the plant results obtained in each process with the same quality of retort-gas tar:

TABLE 9.—*Yield from distillation of coal tar.*

Products obtained.	Distilled to a medium soft pitch.	Distilled to a coke.
	Per cent.	*Per cent.*
Water	2	2
Total distillate	27	61
Pitch	70	0
Coke	0	30
Loss	1	[a] 7
Total	100	100

[a] Lunge reports a loss of more than double this amount.

It can be seen that the percentage of high-boiling substances recovered when coke is produced instead of pitch is increased decidedly. A rather large proportion of this increment is solid; it is pasty, greasy, flaky, and resinlike as it comes from the still. The color of the distillate coming over is greenish red early in the distillation, but later is yellow, orange red, and maroon. The color changes may differ somewhat when other tars are distilled.

The total distillate from distilling coal tar, not pitch, to coke is a heavy, rather viscous liquid at 25° C., and at room temperature 20° C. Tests by the author gave the following results:

Properties of total distillate.

Specific gravity at 25° C., 1.085.

Distillation of 100 grams in an 8-oz. retort (thermometer bulb ½ inch above level of liquid) gave fractions:

	Per cent by weight.
0 to 150° C.	0.00
150 to 210° C.	0.00
210 to 235° C. (oil)	8.22

Distillation of 100 grams in an 8-oz. retort, etc.—Continued.	Per cent by weight.
235 to 315° C. (½ solid)	36.43
315 to 355° C. (pasty)	13.95
Residue (very soft)	41.00
Loss	.40
Total	100.00

The light oils come over at a higher temperature than when the total distillate obtained in the production of medium pitch is distilled. The total distillate of which the analysis has just been given will comply with many specifications for timber-preserving oil without further change or addition; thus the supply of oil for timber preserving is increased greatly. When this tar is distilled to a medium pitch, only about 10 to 20 per cent of the original tar is considered suitable for timber preserving. When coke is made, however, over 60 per cent of the original tar may be so used, or rather will "pass the specifications." This differentiation is made because the light oils that are apparently not present by analysis are actually a part of this oil but distill at higher temperatures.

The coke from this process is open, porous, firm, and hard, either silver gray or shiny black when thoroughly heated to a red heat during distillation. It kindles easily and makes an excellent smokeless fuel. An analysis of the coke obtained above is as follows:

Analysis of coal-tar coke.

	Per cent.
Moisture[17]	1.0
Volatile	2.0
Fixed carbon	96.5
Ash	.5
	100.0

The preferred way to manufacture coke from tar seems to consist of distilling tar to a hard pitch in the usual way and then running the pitch into carbonizing stills, which may be cast-iron or refractory ovens, where the distillation is continued to coke. Wrought-iron or sheel-steel stills buckle and deteriorate rapidly.

The experimental tar still used for distilling and coking tar in the laboratory is shown in figure 11. It is made of pipe and fittings and can be assembled readily or taken apart and cleaned. Almost any size of screw pipe may be used in making such a still, although 3, 4, or 6 inch pipe seems to be best. The offtake pipe should not be less than one-half inch in diameter. Gas burners of the Bunsen type are satisfactory for heating.

In using this apparatus allowance must be made for frothing; therefore the still should be filled only about one-half or two-thirds full of the tar. The temperature should be raised slowly, particularly until all the water has distilled. During the early stages of distillation the delivery pipe may have to be cooled slightly to condense the low-boiling oils. A condenser is not necessary, however, unless the rate of distillation is very rapid and the tar contains considerable water or a high percentage of low-boiling oils.

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[17] Moisture could not have been present in the coke as made.

Do not permit the offtake pipe to become cold enough to permit congealing of the naphthalene and anthracene fractions. It is necessary to warm the offtake or delivery pipe during the latter part of the distillation to prevent plugging by the congealing of high-boiling fractions. It is well to use a shield of sheet asbestos over the top of the still during distillation.

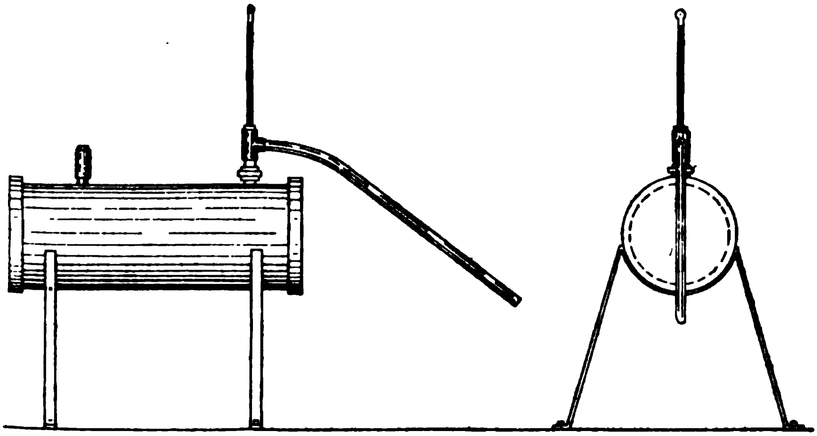

FIGURE 11.—Simple experimental tar still made from pipe and fittings.

WATER-GAS TAR.

In the manufacture of water gas, wherein coke is the main generator fuel, the tar that is produced is entirely a result of the cracking of mineral oil in hot carbureting or checker chambers. The quality and quantity of tar thus produced depend chiefly on the kind and quality of oil used, the temperature in the carbureting chambers, the length of time the oil vapor is in contact with the hot brickwork in the carbureting chambers, and on the atmosphere in which the oil is cracked. Obviously, then, when all kinds of oils are used separately for this purpose, many different grades of tar will be produced. Therefore it is unjust to condemn water-gas tar for certain purposes until full information on the tar is obtained.

Water-gas tars ordinarily have a low specific gravity and contain very little free carbon. Paraffins are nearly always present, frequently in rather large proportions, whereas phenols, tar acids, are present only as traces, if at all.

For many uses to which coal tar and its products are put, watergas tar and its products are apparently unsuitable, but they should not be condemned for all purposes requiring a tar or tar product. Standards giving a tar its high value have changed from time to time and will probably change more. At one time it was thought that carbolic acid in coal tar and in heavy oil made these materials particularly valuable for wood preserving; now it is recognized that phenol does not exist in wood very long after treatment. Likewise, the low free-carbon content of water-gas tar was considered detrimental, but many high-grade by-product coke-oven tars have a still lower average content of free carbon. Some investigators have reported water-gas tars as containing no paraffins, bases, or phenols and little free carbon. The wide variations in important properties existing between water-gas tars made with the various oils no doubt occasions much of the discrimination against water-gas tar. However, it may be said of water-gas tars in general that they are separated from water with difficulty; their pitch is small, easily fusible, and readily affected by temperature changes; they contain paraffins, whose presence increases the difficulty of recovering anthracene, and phenols in minute quantities; and their free carbon content is very low. These tars are used as liquid fuel, for "cutting back" coal-tar pitch to make liquid fuel, for the preparation of waterproofing paints, for road tars, and as fuel for Diesel engines.

The waterproofing qualities and low free-carbon content of water-gas tar would seem to make it very suitable for mixing with coal-tar creosote in preparing wood-preserving oil. Nevertheless its exclusion from such products is usually specified.

In some parts of the country where bituminous coal is used as fuel in water-gas generators the tars produced have still different properties. They are heavy, very viscous, easily separated from water, yield as much pitch as coal tar, and contain as much free carbon as coke-oven tar, or more.

Uniform methods of operation with coal fuel have not yet been adopted, hence a "blanket" recommendation or condemnation of all such tars can not be given.

Table 10 gives analyses of water-gas tars from coal and from coke fuel.

TABLE 10.—*Principal differences in the composition of various water-gas tars.*

	Sample 1.	Sample 2.	Sample 3.
Method of operating	Without blow run.	With blow run.	Coke.
Fuel used	Bituminous coal.	Bituminous coal.	Regular.
Sp. gr. at 15.5° C.	1.17	1.16	1.055
Free carbon ... per cent.	9.14	4.85	Trace.
Moisture ... do.	8.40	3.00	3.00

Distillation of dry tar.[a]

Up to 110° C.	0.0	0.0	0.2
110 to 170° C.	.8	.0	1.2
170 to 235° C.	4.3	1.6	15.7
235 to 270° C.	9.8	7.2	18.7
270 to 300° C.	15.3	9.1	20.6
Residue.	[b] 69.4	82.0	[b] 38.8
Undertermined.	.4	.1	4.8
Total.	100.0	100.0	100.0
Tar acids, per cent.	Trace.	.0	.6

[a] The distillations were made in a 500 c. c. glass distillation flask, with the thermometer bulb at the offtake arm.

[b] Brittle.

A demand for some of these heavy water-gas tars from bituminous coal as a road tar would probably arise if their properties were more generally known. Very little information is available on such tars, and to the writer's knowledge only a few different oils have been employed for carbureting. How wide will be the variety of tars when different gas oils are employed under different operating conditions remains to be seen.

COST AND YIELDS.

Operating costs only are considered here. In deriving them certain assumptions are made, these being based on actual conditions in operating plants. It is obvious that costs are lower in a large than in a small plant, for the efficiency usually is greater and fuel economies are made that are impossible in small works. In a small plant with a 6-ton coal-fired tar still where coal costs $4 a ton delivered and tar 5 cents a gallon, the actual plant costs for labor and materials will be approximately as follows:

Costs at a small tar distillery.

Tar distilled per day—1,200 gallons (12,000 pounds), at 5 cents per gallon	$60.00
Fuel for still—1 ton of coal, at $4 per ton	4.00
Fuel for boiler—½ ton of coal, at $4 per ton	2.00
Labor—engineer and helper	10.00
Total plant costs	76.00

The yield from distilling 1,200 gallons of coal tar is approximately as follows:

Distillation products from 1,200 gallons of coal tar.

	Approximate yield.	Approximate specific gravity.
	Gallons.	
Water and loss	35	....
Crude naphtha	25	0.915
Light oil	50	.985
Carbolic oil	60	1.015
Creosote to a medium soft pitch	190	1.05
Pitch (8,940 pounds)	840	....
Total	1,200	....

The average cost of oil and pitch per gallon is, then, $76.00÷1,165, or 6½ cents. Pitch is usually sold by the ton or by the pound, and consequently the cost computed is $12.21 per ton of 2,000 pounds. Although this is the cost of pitch in bulk, the cost in open-head barrels is not appreciably greater, for tar is usually sold on the basis of gross weight, including the container.

The costs of the paints, stains, disinfectants, road tars, and other tar products discussed in this paper can readily be calculated from the above statement by making proper allowances for the steam, fuel, and labor required in their preparation.

Overhead expenses, repairs and maintenance, and other fixed costs are not included in the figures presented here, as they are not the same in any two plants.

TABLE 11.—*Fractionation of coal tar and some refined and intermediate products obtained.*

First crude distillation of dry tar.	Light oil.	Middle oil (carbolic oil).	Heavy oil (creosote oil and anthracene oil).	Pitch.
Distillation temperatures.	Up to 200 or 210° C.	210 to 240° C.	240 to approximately 315° C.	Above 315° C.
Percentage in tar.	Approximately 5 to 10 per cent by volume.	Approximately 5 to 10 per cent by volume.	Approximately 20 to 30 per cent by volume.	50 to 70 per cent by volume.
Crude commercial products and their uses.	Benzol, solvent naphtha, motor fuel, solvents.	Creosote oil. Crude carbolic acid, disinfectants.	Road oil, wood-preserving oil.	Roofing tars, paving tars. Pitch cement, paints.
Intermediate products by washing and distillation or by expression.	Benzene, toluene, xylene.	Phenol, naphthalene, heavy hydrocarbons, cresol.	Cresol, naphthalene, anthracene, heavy hydrocarbons.	Soft, medium, or hard pitch, coke.
Intermediate chemical products.	Nitro-benzene, aniline salts, aniline oil.	Carbolic acid, picrates, phthalic acid, naphthols, naphthylamine, salicylic acid.	Anthraquinone, alizarin.	
Refined chemical products and and their uses.	Nitrotoluene and other ingredients of explosives, aniline dyes, hydroquinone and other photographic developers, drugs, medicines.	Picric acid, picrates, and other nitrocompounds for explosives; naphthol dyes and colors; artificial indigo; refined carbolic acid.	Alizarin dyes.	

VALUATION OF COAL TAR.

The price that the distiller must pay for coal tar is a matter that is not always under his control, but the relative value of tars at the same price or at different prices is something he must decide, particularly when tar can be obtained from many sources and the supply is greater than the demand. The tar that is most valuable to a distiller in one place might not be exceptionally valuable to a distiller in another place, because the demand for certain tar products is not the same throughout the country. For example, a tar that yields much pitch is perhaps not considered as very high grade, particularly in places where the market for pitch is poor, but in districts where pitch is in demand and tar oils are not, such a tar might be considered most favorably. Other factors of this nature must be considered in purchasing tar. When many products are prepared from tar, a laboratory analysis is necessary in assigning a proper value to a given tar, and even then the problem may not be so simple as in the example cited.

TESTING AND GRADING TAR AND TAR PRODUCTS.

Numerous methods of testing coal tar and its derivaties, some of which are recognized as standard for products used for a definite purpose, have been drawn up by various engineers, chemists, societies, and committees. A series developed by the Barrett Co. has been published in the Journal of Industrial and Engineering Chemistry.[15] The method to be pursued in any particular case in testing, classifying, and grading tar products is frequently prescribed in the specifications for the particular products. Some of these special methods are given in other government publications, including those mentioned on pages 78 and 79. The tar tests which are most frequently made determine the specific gravity of the tar, the percentage of water present, the percentage of and character of the various fractions obtained on distilling the tar, the percentage of residue on distilling the tar, the nature and consistence of distillation residue, the melting point of distillation residue, and the percentage of free carbon present.

Some of the foregoing tests are also made on the crude tar products, with additional tests which determine principally the percentage of solids at a given temperature, the percentage of naphthalene, the percentage of tar acids, the percentage of unsaturated compounds, the distillation range, color, odor, boiling point, physical appearance, viscosity, and flash point.

CONCLUSION.

In this bulletin the author has endeavored to discuss tar products in a general way. The yields and properties of the distillate fractions and residues from tar will, of course, vary with the kind and quality of tar distilled. For example, the distillate fractions from tar, particularly from a low-temperature tar, may represent a greater percentage of the original tar than is shown herein, and vice versa. Likewise, the price of tar is not fixed. Costs of all commodities are changing so rapidly that definite prices can not be given for the various tars. The price of coal tar once ranged from 3 to 4 cents a gallon and that of water-gas tar from 1 to 2 cents a gallon. In general, these prices do not exist at present (1921) except in long-time contracts that have not expired. Water-gas tar which was at one time considered next to worthless now commands a fair price.

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[15] Weiss, J. M., Methods of analysis used in the coal-tar industry: Jour. Ind. and Eng. Chem., vol. 10, 1918, Part I, Crude tars, pp. 732–738; Part II, Distilled tars and pitches, pp. 817–823; Part III, Heavy and middle oils, pp. 911–916; Part IV, Benzols and light oils, pp. 1006–1012.

PUBLICATIONS ON THE UTILIZATION OF COAL.

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BULLETIN 116. Methods of sampling delivered coal, and specifications for the purchase of coal for the Government, by G. S. Pope. 1916. 64 pp., 5 pls., 2 figs.

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TECHNICAL PAPER 123. Notes on the uses of low-grade fuel in Europe, by R. H. Fernald. 1915. 37 pp., 4 pls., 4 figs.

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TECHNICAL PAPER 180. Firing bituminous coals in large house-heating boilers, by S. B. Flagg. 1917. 22 pp., 1 pl., 16 figs.

PUBLICATIONS THAT MAY BE OBTAINED ONLY THROUGH THE SUPERINTENDENT OF DOCUMENTS.

BULLETIN 23. Steaming tests of coals and related investigations, September 1, 1904, to December 31, 1908, by L. P. Breckenridge, Henry Kreisinger, and W. T. Ray. 1912. 380 pp., 2 pls., 94 figs. 50 cents.

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BULLETIN 37. Comparative tests of run-of-mine and briquetted coal on locomotives, including torpedo-boat tests, and some foreign specifications for briquetted fuel, by W. F. M. Goss. 1911. 58 pp., 4 pls., 35 figs. 15 cents.

BULLETIN 138. Coking of Illinois coal, by F. K. Ovitz. 1917. 71 pp., 11 pls., 1 fig. 20 cents.

TECHNICAL PAPER 63. Factors governing the combustion of coal in boiler furnaces, a preliminary report, by J. K. Clement, J. C. W. Frazer, and C. E. Augustine. 1914. 46 pp., 26 figs. 10 cents.

TECHNICAL PAPER 183. New views of the combustion of the volatile matter in coal, by S. H. Katz. 1917. 15 pp., 1 fig. 5 cents.

TECHNICAL PAPER 195. The tars distilled from bituminous coal in hand-fired furnaces, by S. Katz. 1918. 20 pp., 2 pls., 3 figs. 5 cents.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1079

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EXPERIMENTS WITH SPRAY SOLUTIONS FOR PREVENTING INSECT INJURY TO GREEN LOGS.

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USES FOR REPELLENT SPRAYS AGAINST FOREST AND SHADE-TREE INSECTS.

During the past few years there has been an increasing demand for a practical spray that will prevent insect attack to crude forest products such as green saw logs and timbers used in rustic construction. Numerous requests for such a spray are received by the Bureau of Entomology. These inquiries often number more than a hundred through the summer months.

Although many lumbering firms request a spray for this purpose, it is doubtful whether it would be really practical under ordinary conditions. During the flight period of those insects which cause the injury it would be necessary to apply the spray immediately after felling the trees. It is more practical to prevent insect injury in lumbering operations by some alteration in the methods of management, as by more prompt handling between felling and sawing or by submerging the logs in water, than by spraying.

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[1] Resigned December 31, 1920.

Frequently, however, storms blow over many millions of feet of saw timber. Cases are on record where a single firm has lost in such a manner 100,000,000 board feet. It is a physical impossibility to log these trees promptly and get them to the saw or into a place of safety, although from 40 to 60 days' delay may mean total destruction of the sapwood by borers. It might be feasible, however, to saw these trees into log lengths and spray with some solution that would prevent insect attack for two or three months, or until it was possible to haul them to the mill.

The increasing use of the national forests and parks for recreational purposes has resulted in the construction of many rustic cabins. Insects attacking the timbers in these buildings cause annoying exudations of boring dust and loosen the bark so that later it peels off, thus marring the artistic effect. Much of this injury to rustic work could be prevented by cutting the trees at certain periods and by proper seasoning. Frequenters of summer camping grounds can not always plan to cut the trees at the proper time; in fact, it is more frequently the case that the building is constructed during the summer months and the timber felled at that time—a period when the wood is most susceptible to insect attack.

Thus in both situations it is often the case that the more practical and economical means can not be used.

There is also a considerable demand for a suitable repellent spray against certain shade-tree insects. Wood borers attack various species of living trees, causing considerable injury or death. Under certain circumstances a spray could be used advantageously to repel such insects and prevent oviposition. It would necessarily have to be of materials that would not burn the younger bark, although, except for mechanical difficulties, it would only be necessary to apply the spray to the main trunk and larger limbs, since these are the only parts attacked. Spray materials, the cost of which would be prohibitive for the protection of forest products, might be employed on shade trees.

Under circumstances such as the foregoing it is evident that a practical spray for the prevention of insect injury would be of much benefit and its use should result in a considerable saving of forest products and shade trees.

Owing to the many different insects, their different methods of attacking the logs, the many kinds of wood to be protected, and the exposure to weather conditions, the practical solution of this problem presents many difficulties. Several solutions have been found to meet the requirements, except that they are too expensive or too difficult to apply. In the hope that the results so far obtained may be a stimulus for further suggestions or work along this line the problem and the preliminary experiments conducted during the years 1916 to 1919 are here presented.

REQUISITES OF A PRACTICAL SPRAY.

It may be impossible to find a single spray solution that can be used with success under all conditions, but it may be possible to obtain good results by using several solutions, each of which is effective under certain conditions. Any spray to fulfill all the requisites necessary for practical effectiveness must possess the following qualities:

IT MUST BE EFFECTIVE AGAINST SEVERAL TYPES OF INSECTS.

Many species of insects attack green timber. Some attack only certain kinds of wood while others show little discrimination. In some cases the injury is caused by the grubs or larvæ feeding beneath the bark or in the wood, or by an adult which bores through the bark and produces larvæ that feed under the bark. According to their method of attacking the wood, boring insects may be divided into the following four groups:

Type 1. Those that lay eggs in crevices of the bark. The larvæ hatching from these eggs then bore through the bark and later into the wood.

Type 2. Those that gnaw a hole through the bark and insert the egg beneath. The larvæ start feeding directly beneath the bark and later bore into the wood.

Type 3. Those that bore through the bark and wood as beetles, to make a suitable place for developing a new brood. The grubs in this case never cause injury.

Type 4. Those that bore through the bark as beetles and lay the eggs beneath the bark. The resulting larvæ feed beneath the bark and loosen it.

The only spray that could possibly be effective against all these types would be one of a disagreeable odor acting as a repellent, thus driving away the adult beetles and preventing oviposition. Poison sprays that will penetrate the outer layers of bark will kill the young larvæ of type 1, but experiments have demonstrated that such materials are not effective against types 2, 3, and 4. In these types most of the beetles do not eat any of the bark or wood as they chew through it and consequently are not poisoned. Possibly a poison combined with a sticky substance that would form a film over the bark and adhere to the mouth parts of the insects might kill them.

Insects of type 4 are not very injurious to saw logs, as they only work beneath the bark and do not enter the wood, but they are important in loosening the bark from rustic work. The others are all injurious to both classes of timber.

IT MUST BE EFFECTIVE ON VARIOUS SPECIES OF WOOD.

The type of bark makes considerable difference in the application of a spray. A bark which is very absorbent, such as that of ash or, juniper, readily takes a spray; on the other hand, a smooth bark, such as beech or hickory, will absorb scarcely any of it. Such smooth bark does not hold the spray well but allows it to be easily washed off in the rain. In the latter case poison sprays would hardly be effective. The irregularities of the bark and all crevices must be thoroughly covered.

IT MUST NOT BE LEACHED OFF BY RAIN OR OTHER WEATHER CONDITIONS.

One of the greatest difficulties in the experiments to find an effective spray has been that the solutions are soon washed off by rain. Many of those tried were effective for a few weeks, or until the first hard rain, after which the trees were immediately attacked.

IT MUST NOT BE EXPENSIVE.

Since a considerable quantity of liquid is required to cover a large log by spraying, it naturally follows that the material must be inexpensive or it can not be used. Creosote oil, the most effective material so far tried, is far too expensive. It can be diluted, however, with as much as 4 parts of kerosene, thus materially reducing the cost of the spray without diminishing its effectiveness. For rustic work a much more costly spray can be used than on logging operations.

IT MUST FIRST PREVENT ALL INSECT INJURY FOR FROM ONE TO THREE MONTHS AT LEAST.

Three months' protection by the spray would be sufficient for most purposes. It is usually possible to get logs to the mill or into a place of safety within that time. If it were sufficiently cheap so that a second and perhaps a third application could be made, the solution would need to be effective for only one month; the necessity for more than one application, however, would of course be a handicap. In many cases three months' prevention of damage would carry the tree or log through the danger period—that in which the insect is flying—and natural seasoning during the ensuing winter would prevent further injury.

EXPERIMENTS WITH PREVENTIVE SPRAYS.

During the period of insect activities in the years 1916 to 1920, inclusive, series of experiments were conducted at the Eastern Field Station of the Bureau of Entomology, East Falls Church, Va., to determine the effectiveness of various solutions. These were materials recommended by various correspondents or suggested by the forest insect personnel. Dr. J. K. Haywood, chairman of the Insecticide and Fungicide Board, United States Department of Agriculture, also gave some very interesting suggestions.

These experiments are to be considered as only of a preliminary character. The objects were chiefly to determine the requisites of an effective spray and to study the behavior of the different types of insects in relation to various treatments and methods of application, as well as to find an effective spray.

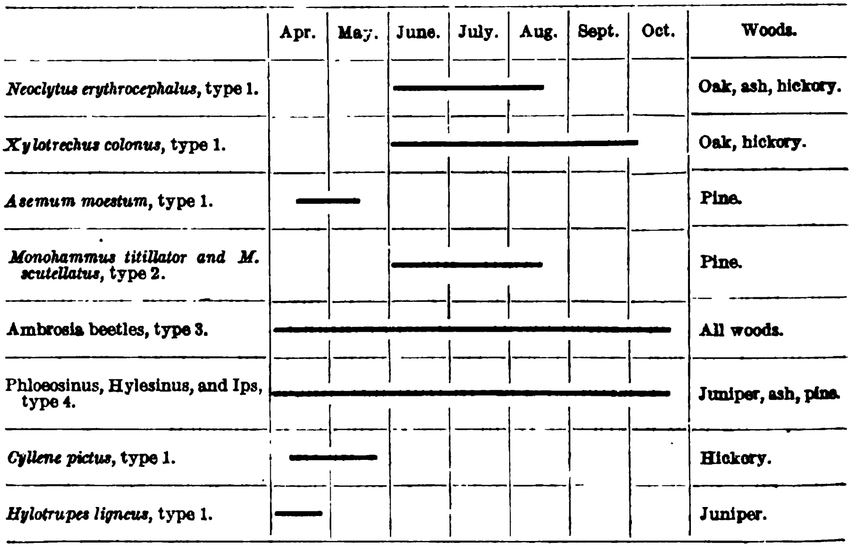
The solutions were tried principally on two kinds of wood—pine and ash—although occasionally hickory, juniper, and oak were used. The wood was cut at a time to give the most favorable condition for insect attack—hickory and juniper about January 1, pine and ash about March 15. It was treated immediately or held in a wire insectary until treated. The individual pieces of wood used were 3 feet long and averaged from 6 to 10 inches in diameter.

Insects of all types were represented in the tests. The following were the most abundant and economically the most important: *Neoclytus erythrocephalus* Fab. on ash and hickory, *Xylotrechus colonus* Fab. on oak and hickory, *Asemum moestum* Hald. on pine, *Cyllene pictus* Drury on hickory, and *Hylotrupes ligneus* Fab. on juniper—all of type 1; *Monohammus scutellatus* Say and *M. titillator* Fab. on pine—both of type 2 (no species of type 2 on other woods); various species of Ips, Phloeosinus, and Hylesinus on pine, juniper, and ash, respectively—of type 4; various species of ambrosia beetles on pine and oak of type 3.

From the foregoing it is seen that pine was tested against all four types; ash against types 1, 3, and 4; hickory against type 1; juniper against types 1 and 4; and oak against types 1 and 3. Owing to the seasonal variations in the abundance of the various species of insects the tests were not conclusive every season. For example, in 1918 and 1919 Monohammus was very abundant and attacked all the controls as well as many treated woods, while in 1920 very few were present and not all control logs were attacked. Again, in 1918 Hylesinus (type 4) in ash was abundant, though in 1920 very few of the control logs were attacked. Every year, however, some one type was very abundant on all species of wood used.

The flight period of these insects has a certain bearing on the results, as those species flying late in the season found the logs after they were exposed to weathering for a month or more. Most of the treatments were made about April 1, or 15 days before the flight of the first insects, and unless otherwise stated this time of treatment is to be inferred. With certain materials treatments were made also on June 1 at the time of the first flight of some other species. The flight periods are given in Table I.

TABLE I.—*Flight periods of beetles used in experiments for the protective treatments of woods with spray solutions.*



	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Woods.
Neoclytus erythrocephalus, type 1.			—	—	—			Oak, ash, hickory.
Xylotrechus colonus, type 1.			—	—	—	—	—	Oak, hickory.
Asemum moestum, type 1.	—	—						Pine.
Monohammus titillator and *M. scutellatus*, type 2.			—	—	—			Pine.
Ambrosia beetles, type 3.	—	—	—	—	—	—	—	All woods.
Phloeosinus, Hylesinus, and Ips, type 4.	—	—	—	—	—	—	—	Juniper, ash, pine.
Cyllene pictus, type 1.	—	—						Hickory.
Hylotrupes ligneus, type 1.	—							Juniper.

In the extreme northern States the flight period of these insects begins from two to four weeks later. In the Southern States the flight period extends approximately from March 15 to November 1 for all species except *Cyllene pictus*.

Two methods of application were employed—spraying and dipping. Dipping on the whole proved the more effective, as every crevice in the bark was reached; it was also more economical, as a smaller quantity of the solution was required. A round-bottomed galvanized trough requiring only 1 inch of solution in the bottom was used for this purpose. The logs were revolved in the trough until all sides came in contact with the liquid. When carefully done, however, spraying was nearly as effective as dipping and answered very well for practical purposes. It required a fine discharge under strong pressure so that penetration in all crevices was secured.

The treated sticks were placed in several positions: (1) In shaded woods on the ground, (2) in the sun on the ground, and (3) on a platform off the ground in the sun. The location of the sticks had considerable bearing on the results. Those in the woods were always more heavily attacked and those off the ground in the sun least attacked. This can be explained by the more rapid seasoning of the wood off the ground in the sun, which thus offered less favorable conditions for beetle attack, and by the fact that many insects will not oviposit on the upper surface of logs directly exposed to the sun. The logs in the woods were likewise exposed to more humid conditions and the solutions probably leached off sooner. It follows that the most severe conditions for dipping and spraying tests were presented by those logs in the woods on the ground, and for this reason the discussion of results obtained is based on the results in treated wood placed in this position. Where there was marked difference in the amount of sunlight or in the sun temperature special note is made of the fact.

The thickness of the bark had a certain bearing on the results. Thick-barked pine logs present much more favorable conditions for the attack of all insects concerned. In some cases a treatment was very effective on thin-barked pine logs whereas treated thick-barked logs became heavily infested. The effectiveness of a treatment, therefore, was judged by the results following in the case of thick-barked logs.

TREATMENTS AND RESULTS.

Creosote oil alone.—Pine and hickory dipped and sprayed. No attack three months after treatments except a few insects of type 4 in crevices of sprayed stick.

Creosote oil and kerosene.—All mixtures of kerosene and creosote oil give a tarry precipitate which must be strained out or allowed to settle before the liquid is used in a spray pump. This material was suggested by Dr. A. D. Hopkins.

Equal parts creosote oil and kerosene.—Pine, ash, juniper, and hickory, sprayed and dipped. Results as in the case of creosote oil alone.

One part creosote oil and two parts kerosene.—Treatment as in the next preceding paragraph. Results as in the case of creosote oil.

One part creosote oil and three parts kerosene.—Pine logs dipped. No attack after three months.

One part creosote oil and four parts kerosene.—Pine logs dipped. No attack after three months.

One part creosote oil and eight parts kerosene.—Pine logjs sprayed and dipped were attacked after two months by a few insects of type 4.

Creosote oil alone and mixtures of creosote oil and kerosene gave excellent results. Everything considered, much better results were obtained with them than with any other material. Dilutions of creosote oil containing from 1 to as many as 8 parts of kerosene were effective, and perhaps an even greater dilution would be effective on absorbent barks such as ash or juniper. These mixtures act as repellents (in no cases were insects observed to oviposit where the liquid was present) and they "stand up" very well in wet weather.

One part water-gas tar distillate[1] *and three parts kerosene.*—Considerably more precipitate results from this mixture than from that of creosote oil and kerosene; consequently it is more troublesome to handle. Pine logs were sprayed and dipped. The results were similar to those with creosote oil.

One part coal-tar road surfacing material and three parts kerosene.—Pine logs dipped with this mixture were attacked after 15 days by insects of type 4 and later their condition was but little better than that of the controls.

---

[1] A distillate prepared from water gas.

Coal-tar emulsion (prepared by Insecticide Board); 1 part emulsion to 10 parts water.—Pine logs dipped and sprayed were attacked after 15 days by insects of type 4 and later by those of all types. Final results were no better than in the case of the controls.

Crude petroleum.—Pine logs sprayed and dipped with crude petroleum were attacked by insects of type 4 after 15 days and later by those of all types. Final results were no better than with the controls.

Anthracene oil emulsion (prepared by Insecticide Board); 1 part emulsion to 10 parts water and 1 part emulsion to 100 parts water.—Dipped pine logs were attacked by insects of type 4 after 15 days and later by those of all types. The final results were no better than with the controls.

Crude solvent naphtha.—Pine logs dipped with this material were slightly attacked by insects of type 4 after 15 days and later by all types. Final results were but little better than with the controls.

Six ounces of nitrobenzene in one gallon of kerosene.—Pine logs sprayed and dipped were attacked after 15 days by a few insects of type 4 and later by more of the same type. The final results were somewhat better than with the controls.

Fish oil.—Pine logs sprayed and dipped were immediately attacked by insects of type 4 and later by all types. Final results were no better than with the controls.

Two parts fish oil, one part pine oil, and three parts kerosene.—Pine logs sprayed and dipped were attacked after 15 days by insects of type 4 and later by all types. The final results were no better than with the controls.

Kerosene.—Pine logs sprayed and dipped were attacked after 15 days by insects of type 4 and later by all types; results were no better than with the controls.

Sulphite concentrate (furnished by a paper-pulp mill); full strength and diluted with equal parts of water.—Pine logs dipped were attacked after one week by insects of type 4 and later by all types. Final results were no better than with the controls.

Spent sulphite; full strength and equal parts spent sulphite and a commercial miscible oil.—The results in pine logs dipped and sprayed were the same as with sulphite concentrate.

Tree gum (furnished by Gipsy Moth Laboratory); 1 pound of tree gum dissolved in 1 quart of turpentine.—Pine logs treated with a brush were attacked by a few insects of type 4 after two months. The results were much better than on the controls, but the material held moisture in the log and produced much bluing of sap when insects penetrated the bark. The sticky film acted as a mechanical barrier.

One pound of melted paraffin with one gallon of gasoline added.—Pine, ash, and juniper logs were sprayed and dipped and placed in a cage for experiment against insects of type 4. This treatment prevented all attack on the more absorbent bark of ash and juniper. A few insects attacked the pine.

One-half pound of naphthalene dissolved in one gallon of gasoline.—Dipped pine logs were attacked after 15 days by insects of type 4 and later by all. Final results were but little better than with the controls. The naphthalene soon evaporates and no odor is left.

One pound of melted paraffin with one-half pound of naphthalene and one gallon of gasoline added.—Pine, ash, and juniper sprayed and dipped and placed in a cage against type 4 were attacked by insects of this type after 30 days.

One per cent sodium arsenate solution.—Juniper logs dipped and exposed against insects of types 1 and 4 were not attacked after 60 days.

Sixteen parts of 1 per cent sodium arsenate and one part of a commercial miscible oil.—Juniper dipped in this mixture was not attacked after 60 days, but dipped pine was heavily infested by type 4 after 15 days.

Stock solution of kerosene emulsion, the water used containing 2 per cent sodium arsenate.—Pine and hickory logs, sprayed, were attacked by all types possible. The final results were no better than with the controls.

One ounce of sodium arsenate dissolved in one pint of alcohol and added to one and one-half gallons of kerosene.—Very little arsenate went into solution. Pine logs, sprayed and dipped, were heavily attacked after 30 days by insects of type 4 and later by all types. Final results were but little better than in controls. Ash logs, sprayed and dipped, were attacked by one insect of type 1, but the final condition was much better than with the controls. This treatment was repeated on June 1 under similar conditions and with similar results.

One part arsenic acid to nine parts water followed by lime water (arsenic acid 30 per cent AS_2O_5 *by weight, S. G. 1.3000, prepared by Insecticide and Fungicide Board.*—Pine and ash logs were dipped. The pine was not attacked until 60 days and then by only a few insects of type 4. The ash was not attacked. This treatment, under similar conditions, was repeated June 1, and there was no attack after 60 days.

One-fourth ounce of corrosive sublimate dissolved in two and one-half ounces of alcohol and added to one and one-half gallons of kerosene.—Pine and ash were sprayed and dipped. The pine was first attacked after 40 days by a few insects of type 4; there was no other attack. The ash was not attacked. This treatment, repeated June 1 under similar conditions, gave the same results. Although these logs were not attacked by Monohammus of type 2, it is hardly safe to conclude that this treatment would always be effective against them.

Saturated solution of sodium fluorid.—Pine, ash, and hickory were sprayed and dipped. There was no attack for 30 days, and then the logs were infested by all types, though to a less degree than the controls. Little bluing was noted on pine. Although not altogether successful, this solution is worthy of further trial. This treatment, repeated June 1 with conditions as before, gave like results.

Saturated solution of sodium fluorid, 20 parts to one part of a commercial miscible oil.—Pine logs were dipped and sprayed with results as in the previous experiment.

Three ounces of zinc chlorid dissolved in three ounces of alcohol and added to one and one-half gallons of kerosene.—Pine and ash sprayed and dipped. The pine was attacked after 30 days by insects of type 4 and later by all types. Ash was not attacked by type 1. June 1 the treatment, under the same conditions, was repeated with results as before.

Five and ten per cent crude carbolic acid[1] *in water.*—Pine logs, sprayed and dipped, were immediately attacked and heavily infested by all types. The final results were no better than with the controls.

Two and one-half per cent solution crude carbolic acid in water, eight parts to one part of a commercial miscible oil.—Treatments and results as in the preceding paragraph.

Six ounces of carbolic acid in one gallon of kerosene.—Pine, sprayed and dipped, was attacked after 30 days by all types. The final results were no better than with the controls.

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[1] Coal-tar oils and acids, 97 per cent; inert matter, 3 per cent.

Carbolic soap solution: One pint crude carbolic acid added to one gallon soft soap, thinned by addition of one gallon of hot water, left to stand overnight, and then diluted with eight gallons of soft water (recommended in literature).—Pine and ash, sprayed and dipped June 1, were attacked by all types after 10 days.

Five per cent solution of nicotine sulphate.—Pine, hickory, ash, and juniper were sprayed, and all were attacked by type 4 within 10 days.

Two teaspoonfuls nicotine sulphate dissolved in three ounces of alcohol and added to one and one-half gallons water.—Pine and ash, sprayed and dipped, were infested by all types after 15 days.

Ten per cent solution of sodium carbonate.—Pine and hickory logs sprayed were immediately attacked by all types possible.

Five per cent solution of a proprietary crude cresol-soap disinfectant.—Pine, juniper, ash, and hickory were sprayed but were all attacked by all types possible.

A strong suspension of whitewash.—Pine logs dipped were heavily attacked after the first rain.

A strong solution of sodium chlorid.—Pine logs sprayed were immediately attacked and their condition was no better than that of the controls.

One part crude pyridin preparation to ten parts water.—This did not mix well. Pine and ash were dipped June 1. After 30 days both woods were infested by all types possible, but were in somewhat better condition than the controls.

One part crude pyridin preparation to ten parts kerosene.—Pine and ash were dipped June 1. After 60 days no insects had attacked either wood. The odor could still be detected on the logs. This material seems to be very promising and deserves further trials.

REMARKS ON POISONS USED.

Several of the more active poisons seem to be effective against certain types of insects, particularly those of type 1. They are especially effective when combined with oils that will penetrate the bark (as the mixture of corrosive sublimate and kerosene) or followed by another solution rendering them insoluble (as arsenic acid followed by lime water). This latter, however, is difficult to apply. They are also more effective when used on absorbent types of bark as ash and juniper.

OTHER EXPERIMENTS WITH INSECTS OF TYPE 3.

The results of the preceding treatments were not conclusive against the ambrosia beetles (type 3) for two reasons: These insects require wood that is moist—at least such wood presents optimum conditions—in which to rear their broods. The logs used in the preceding experiments, averaging only 6 to 10 inches in diameter, often dried so rapidly that they were not suitable for these beetles. At the same time another series of experiments was being conducted in which water-soaked logs were used. These acted as traps, attracting most of the ambrosia beetles.

Consequently, to determine just how effective these solutions were against ambrosia beetles (Table II), the water-soaked logs were thoroughly sprayed with (1) 4 parts kerosene plus 1 part creosote oil, (2) the corrosive sublimate solution as given before, and (3) 1 part crude pyridin preparation to 8 parts kerosene. All the sticks were dried for 24 hours before the sprays were applied. These materials were applied to three pines, one oak, and one ash log, July 28, 1920. The results are given in Table II.

TABLE II.—*Results of experiments in the treatment of water-soaked logs against ambrosia beetles.*[1]

	Controls.			Kerosene and creosote oil.			Pyridin and kerosene.			Corrosive sublimate.		
	Pine.	Oak.	Ash.	Pine.	Oak.	Ash.	Pine.	Oak.	Ash.	Pine.	Oak.	Ash.
Aug. 3	1	1	7	0	0	0	0	0	0	0	0	1
9	0	1	23	1	0	0	0	0	1	0	0	3
13	1	3	27	0	0	0	0	0	0	0	5	6
22	5a	x	x	0	0	1	0	1	0	1a	4	16
27	1a	13	64	1	0	0	0	0	0	1a	0	10
Sept. 1	(2)	(2)	(2)	0	0	0	0	0	0	0	0	4
8	0	1	4	3a	0	0	0	0	1	2a	1	7
18	(2)	(2)	(2)	0	0	2	0	0	0	0	0	1
28	(2)	(2)	(2)	0	0	1	0	0	0	0	0	4
Total ambrosia beetles	2	19	125	2	0	4	0	1	2	1	10	52

[1] Numbers refer to ambrosia beetles attacking except when followed by letter.
[2] Not counted.
a=species of Ips, type 4. x=many ambrosia beetles not counted.

POISONING OF AMBROSIA BEETLES.

To determine whether ambrosia beetles feed on the bark as they bore through it, and consequently whether poison spray could be effective against them, several water-soaked ash logs were dried for 48 hours to remove the excess water from the bark and then completely submerged for 48 hours in a solution of sodium arsenate, 2 pounds to 10 gallons of water.

A wooden frame with a cheesecloth bottom was prepared on the ground, and on supports above this frame a rubber cloth was suspended to keep any rain from reaching the treated sticks. The sticks were placed in the box on the cheesecloth and the cloth was carefully examined every two or three days for dead ambrosia beetles. The treatments were made on May 30, 1920. An untreated control was used in the same position. The results were as follows:

June 8, one dead beetle beneath sticks.
June 15, one beetle boring through bark.
June 23, two beetles boring through bark.
July 23, two to six beetles were in each stick and all galleries contained eggs and various stages of larvæ.

These beetles were evidently not deterred or injured by the poison. At no time were the sticks wet. It is quite probable that the dead beetle found June 8 was not killed by the poison, since no other dead insects were found.

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Treated Timber
— for —
Highway Construction

SERVICE BUREAU
American Wood-Preservers' Association
1146 OTIS BUILDING
CHICAGO

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TREATED TIMBER FOR HIGHWAY CONSTRUCTION

In the present day solution of problems affecting the vast scheme of highway improvement which is confronting us, we are constantly being made to realize, in more ways than one, the truth in the time honored phrase that "The chain is no stronger than its weakest link."

In building our roadways, experience has taught us just what is the best surfacing to use under given conditions, with due regard to finances; old high water marks indicate just how high we must elevate our grade line to insure against inundation; and the general public has come to realize the fact that sufficient right-of-way must be secured, before initial construction is begun, to take care of present theoretical traffic due to improved conditions and to provide for future expansions to take care of coming problematical increases of traffic, which we in our present unenlightened state cannot picture.

We have come to realize that the only permanent feature of a highway is its location, and that the most perplexing problems involved in our efforts towards highway improvements are the questions pertaining to our drainage structures. While conditions affecting type of roadway, grade lines, width of right-of-way and location can be met and mastered by established precedents and past experience, there are many and varied causes which keep the bridge engineer in the "pioneer" class. His problems are as new and changeable as the structures that he is called upon to build, and no two of them may be said to be alike.

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Unfortunately in the past and still more unfortunately in the present, too little attention has in too numerous instances been paid to certain details affecting the usefulness, efficiency, and life of drainage structures.

It is not the purpose of this paper to deal with the relative merits of the several different types of drainage structures and the kinds of material which are used in their make-up, but rather to call attention to one particular source of supply for the construction of our bridges and culverts which presents unlimited opportunities for saving millions of dollars in this vast country-wide movement for the improvement of our roadways.

Unquestionably, we are made to realize, when contemplating the gigantic task which confronts the road builders of today, that he who commented upon the fact that "We are the Ancients" was wise beyond his generation. Some few years ago, when the automobile was the main butt for the joke makers of the country,who could have conceived the traffic conditions of the present? And, following the same line of thought, what can we, with our disjointed and spasmodic attempts at highway improvement, know of what conditions will be in twenty, or even ten years? With the gradual improvement of the uncharted gaps in our vast network of proposed State and National Highways, and the resulting increase of our modern perfected methods of motor transportation, country lanes will become congested thoroughfares. It will then become a comparatively simple matter to widen the traveled way, - but what of the bridges and culverts?

Today, the greater number of bridges constructed provide for single passage roadways, comparatively few being over 16 feet in width. Where State or Federal supervision is employed, the structures are amply strong, as a rule, to meet all requirements, both present and future, when the "future" is limited to a reasonable number of years. But for what duration of time will our heaviest bridges of 15, and, in rare instances, 20 ton capacity prove sufficient in themselves to meet advanced conditions? Will not these bridges of today fail the tests of tomorrow, and prove eventual "Weak Links" long before their mechanical life is over and have to be replaced at great expense?

The question of strength is not the only feature to be considered here, for not only will increased loads require heavier bridges, and the growing volume of traffic necessitate the widening of the structures, but varying drainage conditions will tax the carrying capacity of our natural drains more and more. Increasing rapidity of the run-off of storm waters, caused by deforestation and improved drainage conditions, will require larger openings than are now necessary. There are vast areas of country which will be affected by these improved conditions. Can it be expected that drainage structures, installed today largely by guesswork, will effectively meet these increased requirements of the future?

The question, therefore, arises as to whether or not we should be influenced in constructing our bridges and culverts by these

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unknown factors, and make provision to meet future conditions in an economical and efficient way, so that our drainage structures may be strengthened, widened and lengthened without loss, or whether we should build to meet present conditions, and let the future take care of itself - come what may.

The logical answer to this problem is the use of scientifically treated timber for our drainage structures, both bridges and culverts.

Unlike the other types of permanent construction, timber structures may be widened, strengthened and lengthened at will, without any loss of material or waste, and at comparatively little expense.

Practically, to date, the general use of treated timbers has been confined to a limited field, where extreme conditions have had to be met and overcome. While the large railroad corporations have been aware of the value of this product, and have been using it to advantage for many years, the adaptability of treated timber for highway work in general has not received its due recognition, even though its value as bridge and culvert material is readily conceded by anyone who is experienced in this particular field of endeavor.

Unfortunately, however, the theories of scientific timber preservation are little known to the general rank and file of construction engineers and contractors, and it is often difficult to overcome their skepticism and pry them away from set ideas based upon long established precedent.

One of the first obstacles to overcome in gaining recognition of the value of well preserved timbers is the difficulty of forcing upon the public the realization of the fact that there is a vast difference between "pressure treated" and plain or "untreated" wooden structures.

In this day and time, with the tragedy of our rapidly disappearing forests confronting us, it is criminal negligence and waste to build any structure, which is exposed to the destructive elements of nature, of untreated timber. Not only is it contrary to all questions of economics to install a bridge or culvert of material which will have to be replaced within a few years, but the demands made upon our timber supply by these easily avoidable renewals cause serious inroads on our already overtaxed remaining timber supply. Construction of this sort should be discouraged in all lines of improvement. On the other hand, the preservative treatment, correctly applied in accordance with modern efficient pressure methods, gives an added life of at least five times that of natural wood, which alone means that a new supply of timber could be (and should be) grown during a minimum life of the bridge. These facts, which so closely demonstrate the difference between the timber "before and after treatment",

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must be recognized by the layman before he realizes that the well treated structure is a permanent structure, and is not to be confused and classed with the ordinary wooden bridge.

Once we realize that treated bridges and culverts are properly classified in the list of permanent structures,we can direct our attention with open unbiased minds to the outstanding features which make this form of construction attractive to the practical road builder.

Engineers who have been engaged in the supervision of various types of bridge construction have gained, from experience, a most favorable impression in regard to the particular suitability of treated timber drainage structures in highway work. The most attractive features of this type of construction are:

1. Initial low cost of high grade materials, which are readily obtainable at all times.

2. Ease of transportation and handling, with no risk of loss due to deterioration or damage before installation.

3. Placing of material with a minimum amount of equipment, thereby greatly reducing operating expenses and overhead.

4. The installation of lumber and piling with unskilled, low-priced labor - often locally secured and easily managed.

5. Elimination of all form work and false work, thereby avoiding large items of expense and delay.

6. The reduction of foundation difficulties to a minimum, due to the practicability of driving the treated piling to a proper bearing capacity without additional expense.

7. Absence of necessity of painting at time of erection, or at any other time during the life of the structure, and complete elimination of all possibilities of unsightly workmanship due to poor form work.

8. Ease and low cost of enlarging and strengthening, both in regard to width of roadway and length of structure, when such improvements are made necessary by increased traffic conditions and improved drainage.

9. Reduction of maintenance and upkeep to a minimum.

10, Low initial cost of structure completely installed, with consequent saving of funds which may be advantageously applied to extra roadwork or higher types of surfacing.

11. Progress of work never impeded by adverse weather conditions.

The greatest physical disadvantage to be overcome in the future enlarging of permanent structures will be in regard to the widening of

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roadways. It is now generally recognized that the minimum width of a modern graded road should be not less than twenty-four feet. Yet, but few bridges of today provide for more than sixteen feet of travel way in the clear. With the advent of automobile traffic, this width hardly permits of the safe passing of vehicles upon the structure.

It is the opinion of many that the drainage structures should be as wide as the grade, and the only logical reason for the dangerous practice of narrowing the roadway at the bridges is because financial conditions necessitate a saving being made somewhere. Unfortunately, the efficiency of the drainage structures is made to suffer the burden of this false idea of economy, and while such practices may "get by" at present the day of reckoning is not far ahead when the falsity of this mistaken line of logic will be realized.

Due to the fact that treated timber structures can be installed far more economically than any other type of permanent work, it is now possible to overcome the serious mistake of faulty construction in regard to the width of bridges. In fact, the difference in this cost is so marked that permanent bridges of ample width of roadway can now be installed at equal or less cost than expensive types of so-called permanent structures of insufficient width.

These statements are not mere theorizing, but are based upon actual facts and figures, which can and should be thoroughly investigated by those who are prone to be skeptical.

For anyone to realize thoroughly the extent to which the process of modern treatment actually lengthens the life of timber, it is necessary to make more than a cursory examination of this interesting subject.

From point of service, there are structures which have been in use for over thirty-five years, and which give every indication of still being in use for many years to come.

Instances are on record where treated piling, after years of service under extreme conditions, has been salvaged and redriven in new work of permanent design.

Creosoted culverts, after from twenty-five to thirty years service, have been found to be in perfect state of preservation, and particular mention may here be made of the creosoted trestle constructed by the New Orleans and North-eastern Railroad over Lake Pontchartrain. This trestle, five miles in length, and constructed in salt water, has been in service since 1883 and is still carrying the traffic of this important main line railroad.

There are other existing monuments, too many to cite, bearing silent witness to the efficiency and value of this wonderful source of supply of structural material, but it is not necessary to dwell further, at present, upon their enumeration.

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Attention has been called to the use of treated timber for drainage structures only, not taking into consideration the adaptability of this product for the highest class of surfacing.

Reference is here made to the creosoted wood block type of pavement. Without fear of contradiction, it can be safely stated that, as a wearing surface, this particular material is second to none. Of course, the development of our highway system has not yet advanced to such a point of proficiency that wood block surfacing can be given general consideration, except in the vicinity of large centers of population, where traffic conditions warrant the laying of the highest types of pavements. With the perfecting of our general highway system, and the resulting increase in traffic, both in volume and tonnage, this class of surfacing will be more and more in demand. Its present use, however, outside of street paving, is of necessity confined to the flooring of bridges, for which purpose it is particularly suitable.

No attempt will be made in this paper to discuss the various types of bridge designs, or the method of treatment of timber. Varying conditions affecting different locations will have the effect of determining what specifications should govern in each individual case, and it must be left to the good judgment and experience of the engineer in charge to determine what will give the best results.

So that these "best results" may be attained, both in the interest of the tax-payer and the movement of highway improvement in general, the practicing engineer must familiarize himself with the merits and possibilities of this type of permanent construction, and the student engineer should be educated along the same lines.

To this end, therefore, that the Doctrine of Scientific Timber Preservation may be brought to the attention and appreciation of the public at large - who eventually pay the bills - it is urged that engineers in charge of construction work, as well as those who already know through experience the truth of that doctrine, avail themselves of existing specifications drawn up and adopted after years of study by the American Wood Preservers' Association, American Railway Engineering Association, and others.

These standard specifications, used by the larger consumers of treated wood, insure uniform treatments which give the best results in service, and material treated by them is more readily obtained and at a cheaper price than that treated by non standard specifications.

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U. S. DEPARTMENT OF AGRICULTURE.

FARMERS' BULLETIN NO. 474.

THE USE OF PAINT ON THE FARM.

BY

PERCY H. WALKER,
Chief, Contracts Laboratory,
Bureau of Chemistry.

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LETTER OF TRANSMITTAL.

United States Department of Agriculture,
Bureau of Chemistry,
Washington, D. C., September 20, 1911.

Sir: I submit for your approval a manuscript prepared by Mr. P. H. Walker, chief of the contracts laboratory of this bureau, on the use of paint on the farm, which it is thought may serve a useful purpose by calling attention to the economic importance of painting farm buildings and equipment, and giving such nontechnical directions and discussion as may serve to assist the farmer in the purchase and use of painting materials. The composition of paints can not be discussed to any extent without involving much technical detail, nor is it thought that the farmer can often mix his own paints to any great advantage; for these reasons no attempt has been made to give many formulas. The information given will, it is thought, enable him to purchase the paints economically and apply them intelligently and to the best advantage.

Respectfully,
F. L. Dunlap,
Acting Chief, Bureau of Chemistry.

Hon. James Wilson,
Secretary of Agriculture.

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THE USE OF PAINT ON THE FARM.

INTRODUCTION.

There is probably no one point more neglected by the average farmer than the judicious use of paint, not only on his house and outbuildings, but also on machinery and various agricultural implements. It is perhaps the rule rather than the exception in some sections to see houses and agricultural implements on the farm sadly in need of paint. The idea seems to be prevalent that paint is used solely for ornamental purposes, and its use is regarded as a luxury rather than a necessity. While paint does, of course, serve the purpose of improving the appearance of property, it is far more useful for protection than for ornament. A small amount of money and work expended in keeping a valuable piece of machinery properly painted will add greatly to the length of its life. The same may be said of buildings. Another useful object which is accomplished by painting is the improved sanitary conditions of buildings and outhouses. It is not proposed in this bulletin to give instructions for artistic painting, or even for doing the class of work which would be expected of a first-class master painter, for such work can not be expected of one engaged in another business. But any man can do an average job of painting, and can thereby not only improve the appearance of his place, but can add greatly to the durability of all articles painted. The cost of such work is small, the necessary equipment is not expensive, and with proper care will last a long time. An attempt will be made to give directions for the care of paint and of the necessary tools used in its application and for the proper selection of different paints for various purposes, their preparation and application, and their approximate cost.

Certain terms will be used frequently with a somewhat restricted meaning, and they are therefore defined as follows:

A paint is a mixture of a pigment with a vehicle and is intended to be spread in thin coats for protection or decoration or both.

A pigment is the fine, solid material used in the preparation of paint and is substantially insoluble in the vehicle.

The vehicle is the liquid portion of the paint.

Bearing in mind these definitions, it is seen that while varnish is used very much in the same manner as paint, it could not be properly classified as a paint, because it does not contain any solid particles of pigment. On the other hand, whitewash, which is not ordinarily called a paint (largely because of its cheapness), would comply with this definition very well.

BRUSHES AND OTHER IMPLEMENTS.

The only absolutely necessary implements are brushes. Probably the most generally useful brush is a round one with bristles about 6 inches long. Oval brushes from 2 to 2½ inches wide are also very good for general use, and a great deal of painting is done with 4 or 5 inch flat brushes. Of these three types it is difficult to say which is the best, different painters having their own individual preferences. The advantage of a flat brush is that a greater amount of surface is covered at a stroke, with the disadvantage that the paint can not be as thoroughly rubbed in. On the whole, therefore, it is best to use a round brush. The 6-inch bristles are too long for proper working, and before being used a piece of cloth should be tied around the brush about 4 inches from the end of the bristles and 2 inches from the binding. As the bristles are worn off this sleeve or bridle, as it is called, may be pushed back, thus materially lengthening the life of the brush. For painting sashes and other small surfaces smaller brushes are necessary, the most satisfactory being the small oval brushes with a chiseled end. For varnishing, oval or flat brushes with somewhat shorter bristles are generally used. For the application of whitewash and calcimine a very much larger brush may be used, since these are applied lightly to the surface and are not rubbed in. A flat 8 or 9 inch whitewash brush may be used with practically as much ease as a smaller one.

In addition to the paint brushes, dusting brushes made of stiff bristles are useful for cleaning the surface before painting. For cleaning rusted metal surfaces, steel-wire brushes (2 or 3 inches wide and 6 inches long with wires about 3 inches long) are frequently necessary.

If ready-mixed paints are bought the cans may serve as buckets, but if the paint is mixed from the paste a strong tin bucket large enough to allow for stirring the paint will be necessary. Scraping knives and putty knives are necessary tools for the painter, and it is well to have one or two of each, but a very good scraper can be improvised from a piece of sheet iron, and an old kitchen knife may be ground to a square end and converted into a very serviceable putty knife. A paint strainer is useful. but two thicknesses of cheesecloth tied over the top of a bucket answers practically as well. Paint should be strained before using it.

CARE OF BRUSHES.

Brushes for applying oil paints must be well cleaned after using, though for keeping overnight it is generally sufficient to wrap them in several thicknesses of paper. Some painters keep their brushes overnight by putting them in water. If, however, the brush is not to be used for several days, the paint should be washed out of it. Turpentine is one of the most satisfactory materials for washing a brush, but it is expensive, and a brush can generally be washed as well with kerosene, which is much cheaper. After washing off the paint with kerosene the brush should be rinsed with gasoline or benzin, then thoroughly shaken and well washed with soap and warm water. As soon as this washing is complete the brush should be shaken thoroughly so as to throw as much water out of it as possible and hung up with the bristles down to dry; when dried the brush should be thoroughly protected from dust. If much painting is being done it is less trouble to keep the brushes in turpentine or kerosene. For this purpose hooks should be fastened on the inside of a pail with a close-fitting cover, the brushes being suspended either by holes in the handles or by loops of string, so that the brushes hang in the kerosene or turpentine in the bottom of the pail. The bristles should be submerged in the liquid, but should not touch the bottom of the pail. If kerosene is used for cleansing, it should be removed by shaking the brush and rinsing it in turpentine before using again with paint. Brushes used with whitewash or calcimine should simply be washed and not put in the same liquids in which the brushes used for oil paints are kept. If a brush has been used for shellac varnish it should be kept in alcohol or in the varnish itself. In general a varnish brush may be kept in the varnish in which it is used.

DRYING OF PAINTS.

Water paints such as whitewash and calcimine dry in the ordinary sense; that is, by evaporation of the liquid, which in the case of the two paints mentioned is water. The drying of oil paints, however, is quite different, and in order to understand this attention must be drawn to certain peculiarities of the so-called drying oils. Suppose four plates of glass are coated, one with a thin film of water, another with gasoline, another with a heavy mineral oil, and another with linseed oil, and all four plates are exposed to the air for several days. The water and gasoline will evaporate and leave the plates dry and practically in the condition in which they were before applying the liquid. The plate covered with the heavy mineral oil will be found to be greasy, while the plate covered with linseed oil will also have a coating on it, but this coat will first become tacky and finally set to a hard, varnish-like film. If this experiment is tried with other vegetable oils, such as olive oil, it will be found that some of them behave very much like the mineral oils; that is, there is very slight tendency toward the formation of a coating. Other oils, such as corn and soy bean, will behave in a manner similar to the linseed oil; that is, there will be the formation of a more or less tacky mass, with perhaps the final formation of a varnish-like material. None of the other common oils, however, will form the varnish-like coating so rapidly, nor will the coating be so hard as in the case of linseed oil.

Oils which behave like linseed oil are called drying oils. It will be seen from this illustration, however, that the term "drying" as applied to oil is not similar to the drying which takes place on the exposure of a material wet with water to the dry air. The drying of a substance wet with water is really the removal of the water by evaporation. The drying of a drying oil is a change taking place in the liquid. This change is accompanied by an absorption of oxygen from the air, and the drying does not take place in the absence of oxygen. It is hindered by moisture and hastened by sunlight.

The formation of this varnish-like film by the so-called drying of linseed oil is an exceedingly important operation in the drying of oil paints. Certain substances, compounds of lead and manganese, if dissolved in the oil, hasten drying. Boiled oil which contains compounds of lead or manganese, or both, will dry more rapidly than raw linseed oil. Instead of using boiled oil, however, the drying of the oil in paints is generally hastened by the addition of liquids known as driers. These liquids are composed of compounds of lead and manganese generally thinned with either turpentine or benzin, and are known as japan or japan driers. As before stated, while the use of a drier is necessary in a great many paints, the amount used should be small. It is a rather astonishing fact that many driers, if used in small proportions, will very materially hasten the drying of the linseed oil; whereas if a large amount of drier is added, the drying of the oil is retarded. There is another objection to the use of a large amount of drier, and that is that the film produced is not so durable as one produced by raw linseed oil alone or by the use of a raw oil containing the proper amount of drier. There are a number of other oils which have the property of drying like linseed oil, but none of them is the equal of linseed oil for a paint vehicle.

Bearing in mind these facts, it is seen that an oil paint would consist of the pigment mixed with a drying oil, preferably linseed oil, and generally with the addition of a drier. Some pigments, however, have the property of hastening the drying of linseed oil, and when they are used (red lead, for example) it is unnecessary to add any other drier. The varnish-like film left by linseed oil is for practical purposes insoluble in water. It is not, however, impervious to water. If a bright piece of iron covered with a coating of linseed oil, and afterwards thoroughly dried, is exposed to moisture it will be found that while the iron will not rust so fast as uncoated iron, the rusting will take place to a considerable extent. Other experiments can be performed which will demonstrate that moisture passes through this film with comparative ease. But, if an oil paint is employed—that is, a mixture of pigment and linseed oil—it will be found that the water does not penetrate through the film so rapidly as it does through the linseed-oil film alone. Also the paint film is more resistant to mechanical abrasion. While there is some difference of opinion among experts as to the amount of pigment which should be used in a paint, it is generally considered that the greater the amount of pigment the more resistant the paint film is, provided all the particles of pigment are thoroughly covered with the oil. It would appear, therefore, that a film of oil, while it may seem to be homogeneous even if examined under a high-power microscope, is really porous, and by mixture of the oil with the pigment the pores are more or less completely filled, thus making a more impervious film.

In addition to the linseed oil and drier, paints frequently contain volatile substances, such as turpentine and benzin. The addition of these is largely for the purpose of thinning the paint to a better working consistency, so that it can be spread in thin layers more easily. These volatile substances evaporate almost completely and do not remain behind in the dried film. The only substance remaining which binds the solid particles of the pigment together is the oil.

PREPARATION OF SURFACES FOR PAINTING.

All surfaces should be clean and as dry as possible before the application of an oil paint. Much new wood is very difficult to paint. The resins in such woods as yellow pine and spruce tend to destroy any paint that is laid over them. When possible, it is well to allow a new house to stand unpainted for at least six months or even a year after the woodwork has been completed. By this exposure to the weather the resins are brought to the surface and are either washed away or hardened, and the resulting wood surface is in much better condition for painting than is a new structure. An unpainted house, however, is an unsightly object, and it is often desired to paint a new house at once. Painters adopt several methods of treating new wood; probably the one most universally used is to coat all knots and other places where resin appears with shellac varnish, a solution of gum shellac in alcohol. Another plan is to mix with the priming coat of paint a small amount of benzol (coal-tar naphtha), which is claimed by some excellent authorities on painting to dissolve the surface layer of resins and allow the paint pigment to penetrate into the fibers of the wood, preventing the final forcing of the resins to the surface. After applying the priming coat, all nail holes and cracks should be well filled with putty pressed in hard. Filling in with putty should not be attempted before the priming coat is applied, as it is not likely to stick as well.

In painting iron surfaces all rust and grease should be carefully removed, scraping the surface down to bright metal with wire brushes or sandpaper and finally dusting off all adhering particles.

Painting should be done in warm, dry weather. It is much better to select the summer time for painting than the winter. Not only does the paint not flow so well in cold weather, but the surfaces of the painted objects are more likely to be moist, and a little moisture underneath the paint film, either on wood or iron, is very apt to cause serious trouble.

PAINTING EXTERIOR WOODWORK.

All wood is more or less porous, and the natural result of applying a substance like paint to such a material is that the liquid portion sinks into the wood and leaves a large portion of the solid material on the surface. Also different parts of the wood will differ in porosity, and there will tend to be different amounts of paint left on different portions of the surface. In order to do a good job of painting it is practically always necessary to apply several coats to new wood. The first or priming coat is made thinner than the others, the amount of thinning depending upon the porosity of the wood. For ordinary pine, a paint of proper spreading consistency, when mixed with an equal volume of raw linseed oil, generally furnishes a good material for priming. With very porous wood, such as redwood, more oil may be added. The priming coat should be applied with as much care as any other and should be thoroughly brushed into the wood, the brushing being carefully done so that the paint is evenly distributed, with no tendency to run. It is the custom of many painters to add a great deal of drier and of turpentine to the priming coat, and to apply the other coats almost immediately after finishing the priming. This is not good practice. The paint for priming should consist of the pigment, linseed oil, and a minimum amount of drier, with no turpentine or benzin; and after applying it at least a week and preferably longer should elapse before putting on the second coat.

Three coats at least are generally necessary to make a good piece of work. The effect of the priming coat, if properly applied, is to fill the pores of the wood and furnish a foundation on which to apply the subsequent coats. Owing to the different porosity of different parts of the surface, it is almost impossible to completely fill with one priming coat, and an attempt to get a good effect by applying the finishing coat immediately on top of the priming generally results in failure. A second coat will not penetrate to any very great extent into the wood. It should not, however, dry with a gloss, because a glossy surface does not furnish a good foundation for the next coat. In order to prevent the gloss, most painters add turpentine to the paint for the second coat; the amount used, however, should be small—to each gallon of paint about a half pint of turpentine in hot weather, or a pint in cold weather, is sufficient. The second coat, which of course should have been evenly spread and well rubbed in with the brush, should be allowed to dry somewhat longer than the priming coat. The third, or finishing coat should be one which will dry with a gloss, and for this purpose there should be no turpentine or thinner added to the paint at all. This method is one which is advocated by a large majority of authorities on the painting of wood, but is seldom carried out by painters, the tendency being to add excessive amounts of turpentine or benzin, unduly thinning the paint and making it possible to spread it in thin, even coats with less labor than would be required for the same thinness and evenness when paint of a proper consistency is used.

INTERIOR PAINTING.

For oil painting exposed to the weather (outside painting) it is very important that a durable paint be selected, because even the best painted surfaces in time are destroyed by outdoor exposure. Inside of a house, however, the conditions are radically different. The painted surface is exposed to neither the extreme heat of the summer sun nor to the action of rain and frost to anything like the extent that outdoor painting is. In fact, any paint will last for a very long time inside. The main point in selecting a paint for this work is to choose one which will cover well the article to be painted and which contains colors that are permanent. The actual protective coating may be assumed to last as long as there is any necessity for it. Very light tints or very brilliant colors are likely to fade, and white paints containing a large amount of oil tend to turn yellow in dark rooms. The pigment lithopone, which is not suitable for outside work, can be used with satisfaction for interior painting. Calcimines, the so-called cold-water paints,[1] in which no oil or expensive lead or zinc pigments are used, and which are, therefore, very much cheaper than oil paints, last very well on the inside; in fact, some of the oldest paintings in existence are fresco paintings made practically of calcimine.

For interior work the same directions apply as to outside painting, but it is not so important to have the final coating contain such a large amount of oil as to give a glossy finish. A dull finish is preferred by many people, and since this paint is not to be exposed to severe weather conditions, a larger amount of thinner may be used than for outside work. Also, paint for inside work should dry faster than one for the outside, and a somewhat larger amount of japan drier is generally used.

PAINTING OF METAL.

Tin or other metal roofing, also galvanized iron such as gutters and rain spouts, are very difficult to paint, as often the paint does not stick well. This is probably due to a very thin film of grease left on such material from the process of manufacture, and before attempting to paint a tin roof it is best to scrub it perfectly clean with soap and water or with cloths moistened with benzin, and then thoroughly dry before applying the paint. Galvanized iron may be treated in the same way, but it is much better to let this material stand for some time exposed to the weather before painting. The metal portions of machinery are generally cast iron or steel; wrought iron is rarely used, though it is more durable than steel. Cast iron is not so liable to rust as steel, and also the pieces are frequently thicker than the steel portions of a machine. There is perhaps nothing that actually needs paint for protection as much as the steel and iron portions of machinery. Before painting such material the greatest care should be taken to get the surface perfectly clean. Do not apply paint over rust, but clean thoroughly down to the bare metal with scrapers or wire brushes, and finally with dry scrubbing brushes. It is a mistake to spare labor in preparing a metal surface for paint. All oil and grease should be scrupulously removed, and the metal surface should be absolutely clean and dry before painting. The paint should be well brushed on, carefully filling all cracks.

Two or three coats of any good paint may be used. The paint which is generally supposed to protect iron from rusting better than any other is red lead. This is expensive, however, and rather hard to apply. The color also is some objection, although this can be overcome by mixing some dark pigment with it. The addition of a small amount of lampblack improves the color and the working quality of red-lead paint. A paint made of basic chromate of lead

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[1] See page 21 for recipes for making calcimine.

(so-called scarlet lead chromate, or American vermilion) is even better than red lead as a material for protecting iron. This also is very expensive, even more so than red lead, and while the protection is not so complete with the use of cheaper paints made of iron oxid pigments, on account of the fact that pieces of machinery are very likely to have the paint scratched and injured mechanically, it is perhaps best to use an iron oxid paint for most of such work, because of its cheapness. Any good oil paint will give valuable protection to iron if it is properly applied.

MIXING PAINTS.

Paints may be prepared either by mixing the dry pigments with oil and turpentine or benzin; or the paste pigments may be used. The latter are ground in a small amount of vehicle, generally linseed oil. The best pigments are exceedingly fine powders, and it is frequently a matter of considerable difficulty to mix such a powder uniformly with oil so as to have every particle in contact with the vehicle. On this account it is generally considered much easier to make up a paint from the paste pigments than from the dry, because the former have already been ground in a small amount of oil in a mill. When a can of paste pigment is opened all of it should be used immediately or it should be mixed with some oil and kept covered, since the paste is likely to harden and will then be ruined if exposed.

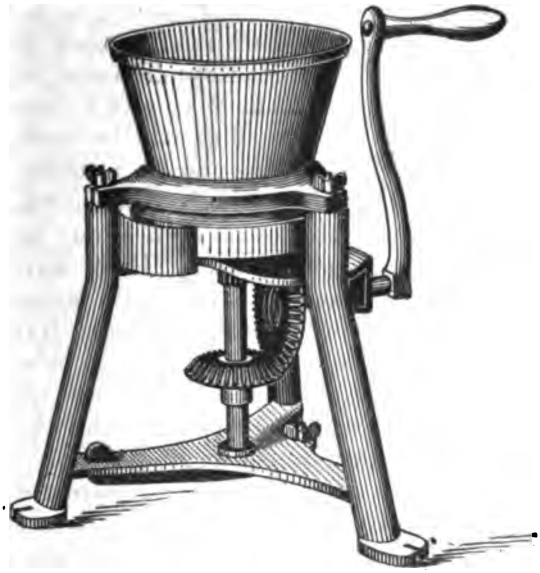
FIG. 1.—A hand-power paint mill.

A very satisfactory hand paint mill (fig. 1) can be bought for less than $10, and with such a mill the dry pigments may be mixed with oil and very satisfactory paints made directly. The claim is made, however, that many pigments require grinding under very heavy pressure to give the best results. Painters, therefore, generally prefer the use of paste pigments rather than the dry for most of their paint mixing. Besides the method of making up paints from the pigments, either dry or in paste form, with the necessary vehicle, the use of ready-mixed paints is very common, and for a small job they have an advantage, for no paint can be made properly without a large amount of grinding or stirring, and this is rather heavy work. The user of mixed paints, however, should have some method of estimating what the material he buys is really worth.

COMPOSITION OF PAINTS AND THEIR COST.

GENERAL DISCUSSION.

It would probably not be denied by anyone that a better paint can be made in a well-equipped factory than by any individual at home or in a small shop. Many ready-mixed paints are of the very best quality, but many are of poor quality, made of cheap materials, and at the same time are sold with extravagant claims and for high prices. The number of different formulæ found on the market is enormous, and no attempt will be made to give a complete or even a representative list of them. An effort will be made, however, to give a few typical formulæ of paints and the methods of calculating the cost of making paints whose composition is known. A very good rule to follow in purchasing mixed paints is to buy nothing which does not bear the name of the manufacturer. If the manufacturer's name does not appear on the label this is very good presumptive evidence that he is not particularly proud of his product. Many State laws require that the composition of paints should also be stated on the labels, and a large number of the best manufacturers do this whether their products are sold in a State requiring such labeling or not.

The most expensive paints are generally white paints or very light tints. The reason for this is that there are comparatively few white pigments which have covering power, i. e., the property of hiding the surface of the material painted. Samples of dry white lead and of dry whiting look much alike. Both are white powders and a thin layer of each appears to be practically opaque. If, however, the two pigments are mixed in oil the whiting is quite transparent, while the white lead is opaque. All of the cheaper white pigments are more or less transparent in oil and are, therefore, deficient in covering power. White lead, zinc white, sublimed white lead, zinc lead, and lithopone are practically the only white pigments which have good covering power in oil. These pigments are all rather expensive, and as they are heavy it takes quite a large amount to make a paint.

Of the dark shades, there are a number of cheaper pigments which have very good covering power. It may be quite safely stated that for a white paint that really covers, some one or more of the white pigments just enumerated must be used. For a dark brown, however, a good covering can be obtained with an iron oxid pigment, which is very much cheaper. Therefore, for such paints there is no reason for using an expensive lead or zinc pigment.

ESTIMATED COST OF WHITE PAINTS.

A vehicle for outside paint of the best quality will generally consist of from 90 to 95 per cent of linseed oil and from 10 to 5 per cent of japan drier. A good japan drier has about the same specific gravity as linseed oil, and each may be considered to weigh about 7¾ pounds to the gallon. Of course, the prices of all paint materials vary, but at the present time linseed oil sells for approximately 90 cents a gallon, and a good grade of japan can be bought for $1.60. In making up paints, the drier should be mixed with the larger portion of the oil before adding the pigment. Using the prices and weights just given for linseed oil and japan drier, the liquid portion of a paint will cost about 95 cents a gallon, or 12¼ cents a pound. White lead, both dry and in the form of paste, costs approximately 7 cents a pound, zinc white approximately 8 cents a pound, and the other white pigments which cover well will not differ very much from these two in price. A gallon of white lead paint will weigh from 21 to 22 pounds. Fourteen pounds of dry white lead and 7¼ pounds of vehicle will make a gallon of paint and at the prices quoted the cost would be about $1.87; 15 pounds of paste lead and 6¼ pounds of vehicle will make a gallon of paint, costing $1.82; 9½ pounds of white zinc and 5¾ pounds of the paint vehicle will make a gallon of zinc white paint costing about $1.46.

Of course, these prices are based on an assumed cost for the ingredients, and to make an exact estimate it would be necessary to know the exact prices of the different materials entering into the paint. Many painters insist that a paint composed entirely of white lead, linseed oil, and drier is the best. Others contend that a mixture of white lead and zinc white is the best, and still others say that a mixture of these pigments with the cheaper white pigments which have slight covering power makes a better paint than the expensive pigments alone. It is probably true that a mixture of lead and zinc is superior to either pigment by itself, and also that the addition of a small amount of so-called inert pigments (silica, whiting, barytes, china-clay, etc.) has no injurious effect on the paint and may even be beneficial. The addition of a large amount, however, of such pigments will give a paint deficient in covering power, and the addition should have the effect of cheapening the product. There is no reason why any mixed paint should cost per gallon more than a paint made entirely of white lead, oil, and the necessary drier. By ascertaining the market price of white lead and linseed oil the buyer should be able to calculate the maximum price for a mixed paint.

Two samples of ready-mixed white paints which were bought at the same time, at practically the same price, will give an illustration of the difference in price of such materials. No. 3361, a white paint, weighed 12.4 pounds to the gallon. The total paint consisted of 63 per cent pigment and 37 per cent vehicle. The pigment contained 30 per cent zinc lead, 13 per cent white lead, 7 per cent whiting, and 50 per cent barium sulphate. Assuming the value of the zinc lead to be the same as that of the white lead, 43 per cent of the pigment was worth 7 cents a pound, and assuming the value of the whiting and barium sulphate to be 1 cent a pound, 57 per cent of the pigment was worth 1 cent a pound. The average price per pound of the pigment would, therefore, be 3.58 cents. A gallon of the paint weighs 12.4 pounds, of which 63 per cent, or 7.812 pounds, is pigment; this, at 3.58 cents a pound, would cost 28 cents. Thirty-seven per cent of vehicle in the gallon of paint will weigh 4.588 pounds. In this paint it consisted of linseed oil and a cheap benzin drier costing about 11 cents a pound, or 50 cents for the vehicle. The total cost of the materials in the paint, then, would be 78 cents per gallon.

Another paint, No. 3864, weighed 14.8 pounds per gallon and consisted of 58 per cent of pigment and 42 per cent of vehicle. The pigment was 55 per cent white lead and 45 per cent zinc white. If the price of these two pigments was 8 and 7 cents, respectively, the average price of the pigment in this paint would be 7.55 cents per pound. Since the gallon of paint weighed 14.8 pounds and contained 58 per cent of pigment, a gallon contained 8.584 pounds of pigment and 6.216 pounds of vehicle. The vehicle in this case was linseed oil and a good grade of turpentine drier. The pigment in this gallon of paint would be worth 65 cents (8.584×7.55) and the vehicle 76 cents (6.216×12.25). The total cost of the materials in this paint, therefore, would be $1.41.

These two paints, as before stated, were bought at the same time and at practically the same price. The prices paid would not be indicative of their value at the present day, since they were bought several years ago, when paint materials were considerably cheaper than they are now; but it is obvious that the margin of profit was very much greater on paint No. 3861 than on No. 3864.

ESTIMATED COST OF COLORED PAINTS.

Tinted paints, at least those of light tint, consist practically of white paint with the addition of a small amount of coloring matter. The coloring materials used in tinting are not uniform, and it is not possible, therefore, to give exact directions for producing a particular shade, since the amount of color used will depend upon the individual characteristics of the particular lot on hand. In general, gray tints are made from white paints by the addition of a black pigment, such as lampblack or bone black, and sometimes a small amount of red or blue is used also. The total amount of coloring matter employed varies, but rarely amounts to as much as 5 per cent. Buff may be made by the addition of mixtures of ocher and umber; brown, by the addition of mixtures of black, red, and sometimes yellow. Yellow and cream may be made by the addition of ocher or chrome yellow; frequently for this purpose golden ocher is used, which is ordinary ocher brightened by the addition of a small amount of chrome yellow. Blue tints may be made by the addition of small amounts of Prussian blue. This is a powerful tinting pigment, and it is seldom that more than 1 per cent is required. With the white paints which contain no lead, ultramarine blue may be used instead of Prussian blue; but ultramarine blue should not be used with lead paints.

Besides the tinted white paints, bright colors are sometimes desired, especially green, for blinds, and reds for the trimmings of houses or for machinery. These paints seldom contain any large amount of the expensive lead and zinc white pigments, but consist of comparatively small quantities of coloring matter and large amounts of the cheap white pigments. For black paints there is practically only one coloring substance, namely, carbon, which, however, occurs commercially in a number of forms. The color of so-called drop or ivory black is carbon, obtained from charred bone; lampblack is carbon in the form of soot. The latter, although very pure, does not make a satisfactory black alone, the heavier forms of carbon, such as bone black or even ground charcoal, producing a better black.

In the following table is given the composition of several tinted paints, and also of bright red, bright green, and black. The composition of individual lots of paint of any of these tints or colors might vary considerably from that given, and the table is only illustrative of the materials from which these different kinds of paints may be made. An estimate of the cost of the raw materials entering into the different formulæ is also included. The total cost per gallon does not make any allowance for labor or for containers, but is based solely upon the cost of the raw materials, assuming that white lead and sublimed white lead cost 7 cents a pound, white zinc 8 cents, and the other white pigments, barium sulphate, china-clay, whiting, and asbestine, 1 cent a pound. The price of the coloring material is given separately for each paint. These prices for the raw materials are a fair approximation of the retail price at the present time. In calculating the cost of the paints per gallon it is assumed that the vehicle in all cases is the same as that described on page 15 and it is valued at 12½ cents a pound. An inspection of the table shows that there is comparatively little difference in the cost of the materials entering into these paints, with the exception of black paint, which is considerably cheaper than any of the others. The red paint is colored by an expensive color, para-red, costing 78 cents a pound; the rest of the pigment, however, is cheap, and it will be noticed that the paint weighs only 11.6 pounds per gallon, whereas some of the others weigh much more.

Composition and cost of tinted and colored paints.

Data.	Tints.						Colored paints.		
	Gray.	Buff.	Yellow.	Drab.	Blue.	Brown.	Red.	Green.	Black.
Percentage composition:									
Vehicle	43.4	43.0	45.0	41.0	43.0	49.0	57.0	34.0	65.0
White lead	....	....	13.0	....	....	12.0	....	....	....
Zinc white	21.0	21.0	25.0	21.0	22.0	24.0	2.0	....	....
Sublimed white lead	27.0	29.0	....	26.0	27.0	....	....	....	....
Barium sulphate	2.0	....	5.0	2.0	2.0	5.0	25.0	49.0	....
China-clay	5.0	....	....	4.0	4.0	....	....	....	....
Whiting	....	....	....	....	....	....	11.0	....	....
Ground slate	....	....	....	....	....	....	....	....	26.0
Asbestine	1.0	1.0	1.0	1.0	1.0	1.0	....	....	....
Color	.6	6.0	11.0	5.0	1.0	9.0	5.0	17.0	9.0
Total pigment	56.6	57.0	55.0	59.0	57.0	51.0	43.0	66.0	35.0
Nature of color	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Weight in pounds per gallon:									
Total	14.7	14.8	14.1	15.2	14.8	13.4	11.6	16.4	10.0
Pigment	8.32	8.44	7.76	8.97	8.44	6.83	4.99	10.82	3.50
Vehicle	6.38	6.36	6.34	6.23	6.36	6.57	6.61	5.58	6.50
Cost per pound, dollars:									
Color	0.05	0.04	0.05	0.05	0.30	0.05	0.78	0.19	0.10
Total pigment	.065	.069	.066	.065	.070	.066	.103	.056	.033
Cost per gallon, dollars:									
Pigment	.541	.582	.512	.583	.591	.451	.514	.606	.116
Vehicle	.782	.779	.777	.763	.779	.805	.810	.684	.796
Total	1.32	1.36	1.29	1.35	1.37	1.26	1.32	1.29	.91

[1] Bone black; tuscan red; ultramarine blue.
[2] Umber and ocher.
[3] Golden ocher.
[4] Ocher and bone black.
[5] Prussian blue.
[6] Bone black; venetian red; chrome yellow.
[7] Para-red.
[8] Five-sixths chrome yellow, one-sixth Prussian blue.
[9] Carbon.

For dark shades of brown or red there is probably nothing which is as cheap as the oxid of iron pigments. These vary very much in shade, giving both browns and dull reds. A pigment that gives a very satisfactory reddish brown and contains about 40 per cent of iron oxid makes a satisfactory paint containing approximately 56 per cent pigment and 44 per cent vehicle, the vehicle being very much the same as that used in a first-class white paint. Such a paint will weigh about 13.5 pounds to the gallon, which, therefore, will contain 7.56 pounds of pigment and 5.94 pounds of vehicle. This pigment is cheap, generally costing not more than 1 or 1½ cents per pound. The pigment in a gallon of this paint, therefore, would cost approximately 10 cents, and the 5.94 pounds of vehicle about 73 cents, giving a cost of 83 cents for the gallon of paint.

An inspection of these figures shows that the expensive part of this paint is the vehicle and not the pigment. A paint of this character is a very good material to apply either to wood or iron. There are more expensive paints, however, frequently used on iron to protect it from rusting, the most popular being red lead and linseed oil. This material undoubtedly affords very good protection, but it is also expensive. A red-lead paint can not be made and kept as most other paints can. The red lead itself causes the oil to dry, and no additional drier is necessary. In fact, red lead should not be mixed until just before it is used. A paint made of 70 per cent of red lead and 30 per cent of linseed oil will weigh about 19.8 pounds to the gallon. A gallon of paint, therefore, will contain 13.86 pounds of red lead, which costs about 8 cents a pound, making the cost of the pigment in a gallon of this paint approximately $1.11. The 30 per cent of linseed oil will weigh 5.94 pounds, and a gallon of linseed oil 7.75 pounds, costing about 90 cents at the present time, or 11.5 cents a pound. The oil in the paint will cost then about 68 cents, and a gallon of red-lead paint would cost $1.79, as compared with 83 cents for a gallon of oxid of iron paint. These two paints will cover about the same area of clean iron, and while somewhat better service might be expected from the red-lead paint, it is more than twice as expensive as the iron-oxid products.

WHITEWASH.

Whitewash is the cheapest of all paints, and for certain purposes it is the best. Lime, which is the basis of whitewash, makes a very sanitary coating, and is probably to be preferred for cellars and the interior of stables and other outbuildings. The following directions for making whitewash are taken from "White Paints and Painting Materials," by W. G. Scott:

> Ordinary whitewash: This is made by slaking about 10 pounds of quicklime with 2 gallons of water.
>
> The lime is placed in a pail and the water poured over it, after which the pail is covered with an old piece of carpet or cloth and allowed to stand for about an hour. With an insufficient amount of water, the lime is "scorched" and not all converted into hydrate; on the other hand, too much water retards the slaking by lowering the heat.
>
> "Scorched" lime is generally lumpy and transparent, hence the use of the proper amount of water for slaking and an after addition of water to bring it to a brush consistency.

Factory whitewash. (*Interiors*): For walls, ceilings, posts, etc.

(1) Sixty-two pounds (1 bushel) quicklime, slake with 15 gallons water. Keep barrel covered until steam ceases to rise. Stir occasionally to prevent scorching.

(2) Two and one-half pounds rye flour, beat up in ½ gallon of cold water, then add 2 gallons of boiling water.

(3) Two and one-half pounds common rock salt, dissolve in 2½ gallons of hot water.

Mix (2) and (3), then pour into (1) and stir until all is well mixed.

This is the whitewash used in the large implement factories and recommended by the insurance companies. The above formula gives a product of perfect brush consistency.

Weatherproof whitewash. (*Exteriors*): For buildings, fences, etc.

(1) Sixty-two pounds (1 bushel) quicklime, slake with 12 gallons of hot water.

(2) Two pounds common table salt, 1 pound sulphate of zinc, dissolved in 2 gallons of boiling water.

(3) Two gallons skimmed milk.

Pour (2) into (1), then add the milk (3) and mix thoroughly.

Lighthouse whitewash: (1) Sixty-two pounds (1 bushel) quicklime, slake with 12 gallons of hot water.

(2) Twelve pounds rock salt, dissolve in 6 gallons of boiling water.

(3) Six pounds Portland cement.

Pour (2) into (1) and then add (3).

NOTE.—Alum added to a lime whitewash prevents it rubbing off. An ounce to the gallon is sufficient.

Flour paste answers the same purpose, but needs zinc sulphate as a preservative.

Molasses renders the lime more soluble and causes it to penetrate the wood or plaster surface; a pint of molasses to 5 gallons of whitewash is sufficient.

Silicate of soda solution (about 35° Baumé) in the proportion of 1 to 10 of whitewash produces a fireproof cement.

A pound of cheap bar soap dissolved in a gallon of boiling water and added to about 5 gallons of thick whitewash will give it a gloss like oil paint.

An old receipt for whitewash, issued by the Lighthouse Board of the Treasury Department, said to be very good for outdoor exposure, is as follows:

Slake half a bushel of unslaked lime with boiling water, keeping it covered during the process. Strain it and add a peck of salt, dissolved in warm water; three pounds of ground rice put in boiling water and boiled to a thin paste; half a pound of powdered Spanish whiting and a pound of clear glue, dissolved in warm water; mix these well together and let the mixture stand for several days. Keep the wash thus prepared in a kettle or portable furnace; and when used, put it on as hot as possible, with painters' or whitewash brushes.

The washes which contain milk, flour, or glue are not to be advised for use in damp, interior places, owing to danger of decomposition of the organic matter. For such locations it is better to use one of the formulæ containing none of these ingredients. Whitewash is applied with a broad whitewash brush and is spread lightly over the surface, no attempt being made to brush it in as is the case with an oil paint.

CALCIMINE.

Cold water paints or calcimine have as their basis whiting or carbonate of lime instead of caustic lime, as in whitewash. This material itself does not adhere, and it is necessary to use a binder of some kind, generally glue or casein. Scott also gives the following directions for making calcimine:

Ordinary white stock. (*Calcimine*): (1) Sixteen pounds dry Paris white (whiting) mixed until free of lumps, with 1 gallon boiling water.

(2) One-half pound white sizing glue; soak 4 hours in one-eighth gallon cold water. Dissolve on a water-bath (gluepot) and pour into (1).

The above recipe makes about 2 gallons of stock, weighing 12¾ pounds per gallon. It is of proper brush consistency and may be used at once, but is better after standing half an hour. Any tint may be given the white stock by stirring the desired dry color in a little water and adding sufficient liquid color to the base.

The following data in regard to the covering capacity and time of applying was obtained as an average of several years' work from shop records:

One gallon covers on plaster=270 square feet.
One gallon covers on brick=180 square feet.
One gallon covers on wood=225 square feet.

A man in 1 hour, using a 5-inch brush, will coat the following amount of surface:

Rough walls=22 square yards (198 sq. ft.).
Smooth walls=38 square yards (342 sq. ft.).
Brick walls=20 square yards (180 sq. ft.).
Flat surface (bench or floor) = 40 square yards.
Ceiling (with stepladder) = 25 square yards.

Damp-proof calcimine. (*White stock*): For plastered walls. (1) Sixteen pounds Paris white or extra gilder's whiting, 1 gallon boiling water.

(2) One-half pound white sizing glue, soak 4 hours in one-half gallon cold water, then dissolve on a water bath.

(3) One-fourth pound phosphate of soda, dissolve in one-eighth gallon boiling water.

Mix (3) with (1), then add (2).

If a thick white stock is wanted, use half a gallon of water with the 16 pounds of Paris white instead of one gallon. For tinting, use colors that are not affected by lime, namely, yellow ochers, sienna, umbers, Venetian red, para-red, maroon oxid, ultramarine blue, ultramarine green, chromium oxid, bone black, etc.

If lampblack is used for tinting, it must be stirred up in hot water containing a little soap or in cold water containing a little borax, the alkali overcoming the greasy nature of the lampblack.

PRECAUTIONS TO BE OBSERVED IN PAINTING.

Do not use any paints containing compounds of lead about stables or outbuildings where the fumes from decaying organic matter occur, since these gases are likely to darken the lead paints. Do not use with lead compounds any pigments which may liberate compounds of sulphur. For example, ultramarine blue which contains sulphur in a form in which it may be set free is a beautiful and very permanent blue and may be used with zinc white, but should not be used with white lead or any other lead pigments. Prussian blue, on the contrary, does not contain sulphur and may be used with lead pigments.

Remember that turpentine and benzin are very inflammable, and especial precautions should be taken not to bring paint containing these substances near any light or open fire.

Many pigments are poisonous, and the workman should be particularly careful to remove all paint stains from the skin, and not under any circumstances allow any of it to get into his mouth. A man should not eat in the same clothes in which he has been painting, and before eating should not only change his clothes but wash all paint stains from his skin. It is not advisable to use turpentine or benzin in removing paint stains from the hands, but by oiling thoroughly with linseed oil, or, in fact, with any fatty oil, and then thoroughly washing with soap, the paint may be removed, provided it has not been allowed to dry too thoroughly on the hands.

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DEPARTMENT OF THE INTERIOR, CANADA

HON. ARTHUR MEIGHEN, Minister; W. W. CORY, Deputy Minister

5

FORESTRY BRANCH—BULLETIN No. 67

R. H. CAMPBELL, Director of Forestry

Creosote Treatment of Jack Pine and Eastern Hemlock for Cross-ties

BY

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CREOSOTE TREATMENT OF JACK PINE AND EASTERN HEMLOCK FOR CROSS-TIES

INTRODUCTION

The rapidly decreasing supplies of the more durable tie woods, the rising cost of tie material and the serious drain upon the forest resources of Eastern Canada which results from the large quantity of timber annually cut for tie purposes have directed the serious attention, both of the railways and of those interested in the maintenance of the timber wealth of the country, to preservative treatment as a means of lengthening the life of ties in service.

Decay and mechanical wear are the causes of the removal of ties from track and while mechanical wear is a factor of great importance in this connection the primary cause of failure in the great majority of cases is decay. By means of efficient preservative treatment decay can be prevented or very greatly retarded and consequently the life of the tie in service can be increased.

In connection with mechanical wear the question of heaving of track and the consequent shimming, which necessitates the frequent drawing and re-driving of spikes, has frequently been brought forward as a serious objection to the use of treated ties in Eastern Canada. It has been claimed that where shimming is done ties are often spike-killed before they fail from decay and that preservative treatment under these circumstances would be merely a waste of money. A point of the greatest importance is that heaving does not necessarily entail shimming. Shimming is only necessitated at certain points where unsatisfactory drainage conditions, combined with the presence in the sub-grade of heavy clay or other soil with high water-holding capacity, cause unequal heaving of a marked character which renders the track unsafe. These points are practically the same every year and are therefore in most cases known beforehand from previous experience. Only a relatively small proportion of the total number of ties in track is subject to shimming. Further, trouble from this source is being gradually eliminated owing to improvements in drainage.

Prior to the war the number of ties annually purchased by Canadian railways for renewals and new construction was from nineteen to twenty millions. The cessation of work on new construction brought about by the war has materially reduced the consumption during the past few years. For renewals alone however from eight to ten millions are required yearly.

It is believed that treated ties were first used in Canada about 1906. Since that date a small number have been used each year, this number, however, never exceeding 10 per cent of the annual consumption. A large proportion of these have been imported from the United States in the treated condition.

The first commercial treating plant in Eastern Canada was erected in 1911. There are now three such plants in Eastern Canada located at Trenton, Ont., Fort Frances, Ont., and Sydney, N.S., respectively, and three in Western Canada, located at Transcona (Winnipeg, Man.), Vancouver, B.C., and North Vancouver, B.C.

The principal native timbers used for tie purposes in Eastern Canada at the present time are in order of importance: jack pine (*Pinus Banksiana*, Lam.); eastern cedar (*Thuja occidentalis*, L.); eastern hemlock (*Tsuga canadensis* (L.); Carr.); tamarack (*Larix laricina* (Du. Roi) Koch) and the several species of eastern spruce (*Picea* sp.). In addition smaller amounts of hardwoods are used, the most important being birch, maple and beech.

The question of the more extensive utilization of hardwoods for tie purposes is occupying a good deal of attention at the present time. Considerable quantities of hardwoods are to be found on lands from which the coniferous growth has been removed by logging or on which it has been destroyed by fires, the hardwood growth then replacing the former stand. Hardwoods, on account of their relatively high mechanical strength, make very good ties provided they are properly handled in seasoning and receive a suitable preservative treatment. The latter, on account of rapid decay of hardwoods in exposed service, is absolutely necessary. The problem of the utilization of hardwoods for tie purposes in Canada presents several difficulties, however, and while it is possible that the use of hardwood ties on a large scale may be a development of the future the coniferous woods are of much greater importance at the present time.

Of the coniferous tie timbers eastern cedar ranks highest in regard to natural durability and lowest as regards mechanical qualities. It is therefore questionable whether it would be economical to treat ties of this wood for main track service under Canadian conditions. In regard to tamarack the available supply is small and is rapidly being exhausted, much of the timber now cut being obtained from dead trees. The ravages of the larch sawfly largely account for this state of affairs. With regard to jack pine, hemlock and the spruces there is no doubt that an efficient preservative treatment would result in considerable financial saving to the railways. Further, when it is considered that jack pine and hemlock together constitute over 50 per cent of the total number of ties annually used in Eastern Canada in ordinary years, the reduction of the drain on forest resources which could be brought about by materially increasing the life of these ties is of considerable importance to the country at large. In view of the above it was decided to devote attention to the treatment of jack pine and hemlock before dealing with other woods.

Little or no reliable information is available as to the adaptability of Canadian jack pine and hemlock to creosote treatment. The lack of such information might lead to unsatisfactory results from treated ties of these species which could be avoided if such information was available. The object of the investigation therefore was to determine how these woods would respond to creosote treatment, what depth of penetration could be obtained and, if necessary, to work out an efficient and economical method of impregnating each. Creosote oil was selected as the preservative because it is the most widely used and most generally efficient material at present employed for the preservation of railway ties both on this continent and in European countries.

The investigation was carried out at the experimental treating plant of the Forest Products Laboratories of Canada, maintained by the Forestry Branch of the Department of the Interior at McGill University, Montreal. This plant is equipped with all the necessary apparatus for the preservative treatment of timber on a small scale by processes within the present limits of commercial practicability.

The laboratories desire to express their thanks to several Canadian railroads and also to the Canada Creosoting Company for rendering valuable assistance in the securing of information and experimental material.

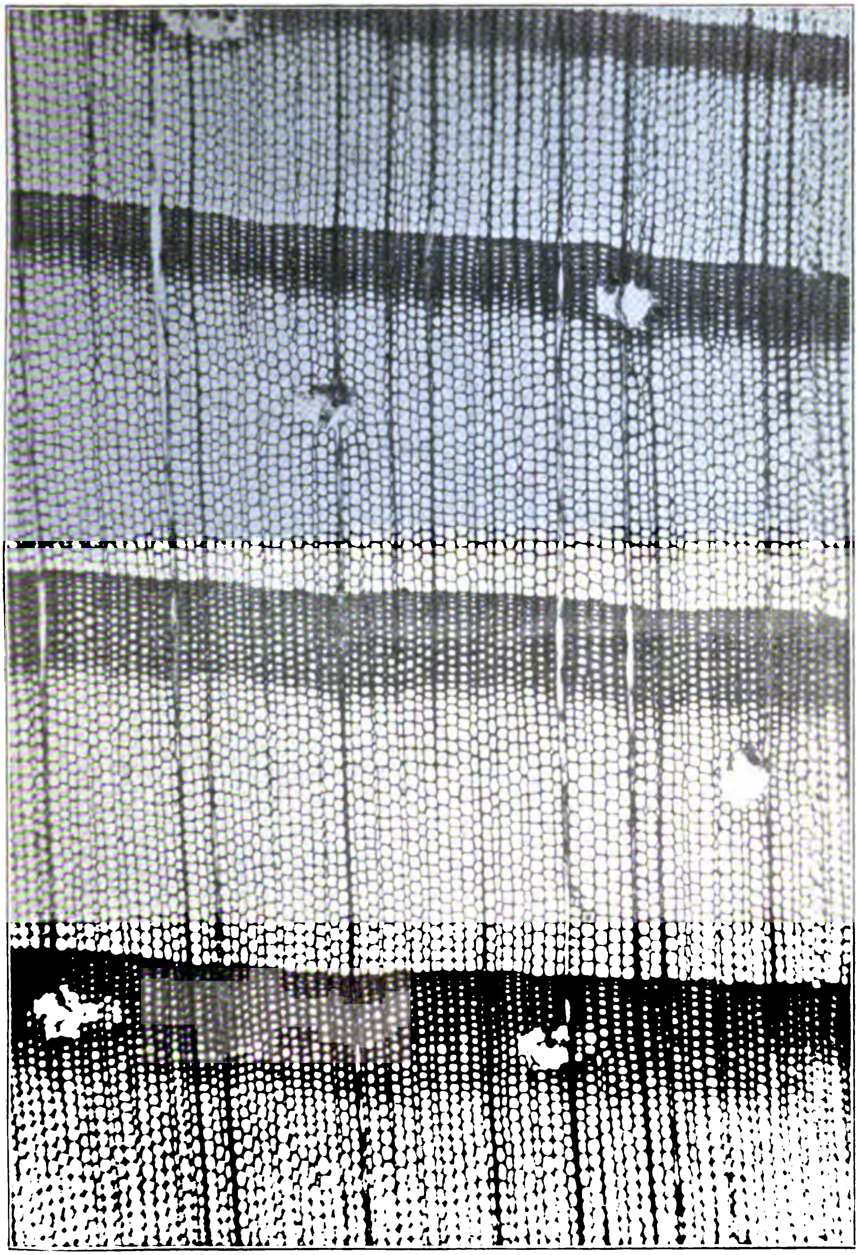
CHARACTERISTICS OF JACK PINE AND HEMLOCK

STRUCTURE

These two species are representative of two different classes of structure occurring in our coniferous timbers. The outstanding point of difference between these two classes is that in the one (to which jack pine belongs) the wood is normally traversed by vertical and horizontal resin canals while in the other (which includes hemlock) these are normally absent. (See Plates 1 and 2.) The presence of resin canals in a wood usually facilitates penetration of the preservative in treatment to some extent

The extent to which penetration is facilitated however varies greatly even in the different species in which resin canals normally occur, being apparently dependent on the size and relative frequency of the canals, on the presence or absence of constrictions, tyloses, and resin therein and on the character of the surrounding tissue. Further,

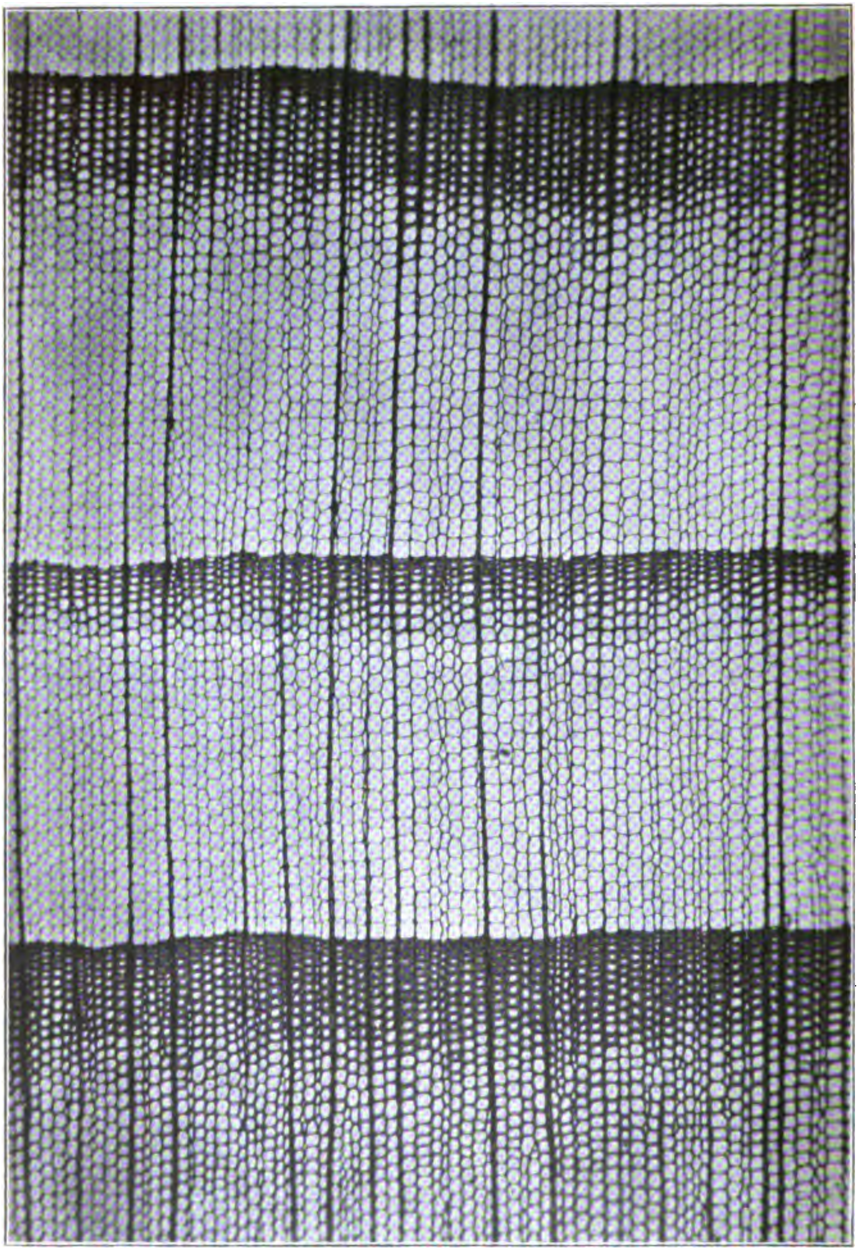
Plate I



Cross-section of jack pine wood magnified fifty times. Note resin canals (large openings).

some coniferous woods without resin systems have been found more easily penetrable than others with resin systems. It is probable that the resin canals in jack pine facilitate penetration appreciably.

Plate II



Cross-section of eastern hemlock wood magnified fifty times. Note absence of resin canals.

STRENGTH

The most important strength functions of a wood for tie purposes are compression perpendicular to grain, compression parallel to grain, hardness, static bending and

TABLE I.—Comparative strength values for various coniferous tie timbers used in Eastern Canada[1].

Species.	Seasoning.	Rings per inch.	Proportion of summer-wood.	Specific gravity, based on weight when oven dry, and		Weight per cubic foot, as tested.	Moisture content, based on weight of wood when oven dry.	Static Bending.				
				on volume when tested.	on volume when oven dry.			Fibre stress at elastic limit, per square inch.	Modulus of rupture per square inch.	Modulus of elasticity per square inch.	Work in bending per cubic inch of specimen. To elastic limit.	Work in bending per cubic inch of specimen. To maximum load.
			per cent.			lb.	per cent.	lb.	lb.	1,000 lb.	inch-lb.	inch-lb.
Pine, jack	Green.	7	30	0·39	0·46	50	105	3,000	5,400	920	0·55	5·9
Cedar, white	Green.	23	36	0·29	0·32	28	55	2,600	4,200	640	0·60	5·7
Hemlock, eastern	Green.	20	31	0·38	0·44	48	105	4,200	6,700	1,120	0·88	6·8
Tamarack	Green.	20	38	0·49	0·56	47	52	4,200	7,200	1,240	0·84	7·2
Spruce, red	Green.	17	27	0·38	0·41	34	43	3,400	5,700	1,180	0·56	6·1
Spruce, white	Green.	14	27	0·36	0·43	33	46	3,300	5,400	980	0·66	5·7

Species.	Impact Bending.			Compression parallel to grain.		Compression perpendicular to grain.	Hardness. Load required to imbed a 0·444-inch sphere of steel to one-half its diameter.		
	Fibre stress at elastic limit, per square inch.	Work in bending to elastic limit, per cubic inch of specimen.	Height of drop of 50-pound hammer causing complete failure of specimen.	Compressive stress at elastic limit, per square inch.	Crushing strength at maximum load, per square inch.	Compressive stress at elastic limit, per square inch.	Radial surface.	Tangential surface.	End surface.
	lb.	inch-lb.	inches.	lb.	lb.	lb.	lb.	lb.	lb.
Pine, jack	7,800	3·3	30	2,250	2,580	380	370		380
Cedar, white	5,300	2·0	15	1,420	1,990	290	230		320
Hemlock, eastern	7,900	2·8	20	2,710	3,270	500	410		510
Tamarack	7,800	2·7	28	3,010	3,480	480	380		400
Spruce, red	7,200	2·3	18	2,360	2,740	350	350		420
Spruce, white	6,800	2·0	20	2,280	2,380	270	280		300

---

1 "Mechanical Properties of Woods grown in the United States," by J. A. Newlin and T. R. C. Wilson, United States Department of Agriculture Bul. 556.

impact bending. The strength of jack pine and hemlock in these functions is stated in Table 1, the values for some other species commonly used for ties being included for comparison.

DURABILITY

Reliable data as to the relative durability of Canadian commercial timbers are at present lacking. Hemlock however is amongst the least durable of our coniferous woods in exposed service, jack pine being somewhat more resistant to decay. For tie purposes in main track the average life of some coniferous species, as reported to these laboratories by several Canadian railroads, is stated in Table 2.

TABLE 2—Average life of untreated ties in main track service in Eastern Canada

Species.	Life in Years.
White cedar	11+
Jack pine	7
Tamarack	7
Hemlock	6

EXPERIMENTAL MATERIAL

TIMBER

The investigation was started with 160 ties of both species and of Canadian growth. The exact origin of this material is somewhat doubtful but it was selected from shipments of ordinary commercial ties originating in Ontario and Quebec and about to be used for replacements. After a considerable amount of work had been done it was found that, owing to lack of uniformity in the experimental material due to checks, shakes, incipient decay, sapwood per cent, knots, moisture content, etc., interpretation of results was obscured to such an extent that reliable conclusions as to the penetration obtainable by different processes could not be reached. Test pieces, also of Canadian growth were then employed. These were carefully selected so as to be sound, strictly heartwood, free from large knots, shakes, checks and other defects, comparable as to rate of growth and of an average moisture content similar to that of the tie material. Heartwood was selected because it was found in preliminary tests to be more difficult to impregnate with creosote oil than was sapwood. These test pieces were found highly satisfactory as they permitted all the work to be carried out on material of a relatively uniform character, facilitated interpretation of results, allowed a much larger number of units per cylinder charge and, consequently, enabled more reliable conclusions as to penetration obtainable by different processes to be drawn from the work. Throughout the remainder of the investigation such test pieces were exclusively used and all results reported herein are based on the same. It should be noted that heartwood in test pieces of this character differs in no respect from heartwood on the faces of ties of the same species and consequently there is no reason whatever why the average results obtained, as regards penetration, in a large number of test pieces should not apply to ties.

PRESERVATIVE

The preservative used was a coal tar creosote oil employed commercially for the treatment of railway ties. The specific gravity at 60° C. was 1·041. Distilled by the United States Forest Service method it yielded the following fractions:—

Temperature Interval.	Per cent.
0° – 205° C.	17·21
205° – 255° C.	36·30
255° – 295° C.	11·76
295° – 320° C.	7·35
Residue and loss	27·38

EXPERIMENTAL METHODS

Each cylinder charge consisted of about twenty test pieces. Moisture content (based on oven-dry weight), volume, and absorption of preservative per cubic foot were determined for each individual test piece. Penetration was determined by sawing the test pieces lengthwise into four parts after treatment as indicated in Fig. 1. The freshly sawn surfaces of each quarter were then planed and penetration estimated. The most characteristic quarter was then retained for reference purposes and photographing. This procedure permits of a very accurate estimation of the penetration from all surfaces of the test piece.

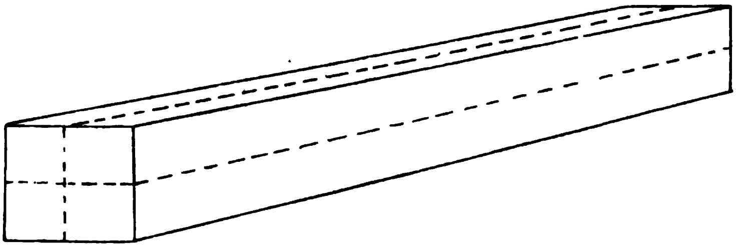


FIG. 1—Method of sawing test piece, after treatment, to inspect penetration.

EXPERIMENTAL DATA, PART I

PENETRABILITY OF JACK PINE AND EASTERN HEMLOCK

JACK PINE

A considerable number of charges of jack pine, each consisting of about twenty pieces 4 or 5 feet by 4 inches by 4 inches, were first treated by various processes in commercial use. It was found, early in the work, that jack pine was very readily penetrable by creosote oil and that satisfactory penetration could be secured by several processes in common commercial use even when the moisture content of the outer layers of the wood was as high as 32 per cent on an oven-dry basis. The approximate weight per cubic foot of jack pine containing various percentages of moisture is shown in Fig. 2. Jack pine material weighing approximately 35 pounds per cubic foot was found to be in good condition for creosote treatment.[1]

Typical results as to penetration obtained in jack pine, using pressure periods ranging from half an hour to two hours are stated in Tables 3, 4 and 5. In the treatments, the results of which are reported in these tables, temperature of the creosote during treatment was approximately 185° F.; maximum pressure was 175 pounds per square inch and was reached in about 40 minutes. A final vacuum of 26 inches was maintained for 15 minutes.

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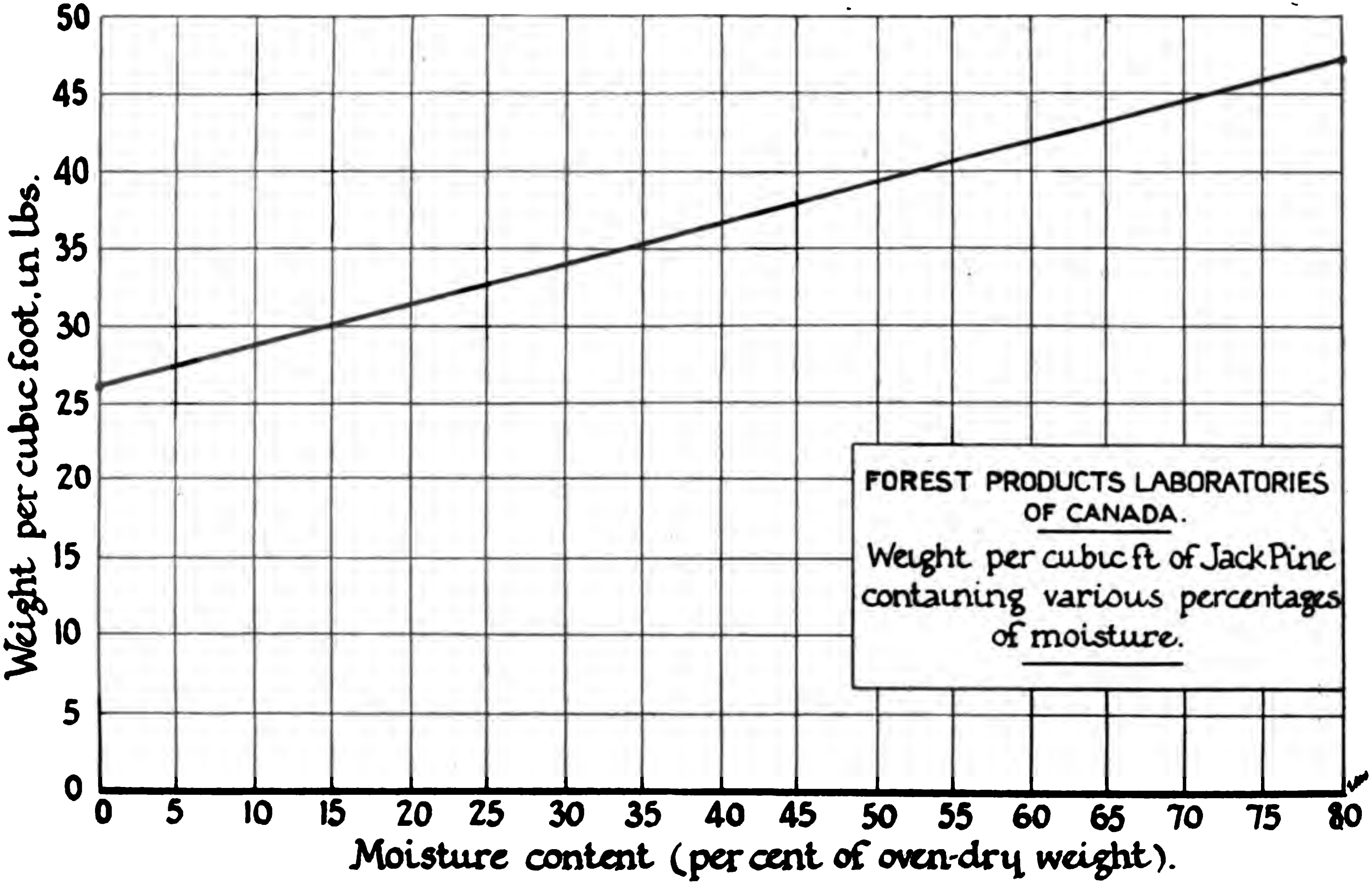
[1] A seasoning study, with the object of ascertaining the seasoning period necessary to dry both jack pine and hemlock of Canadian growth to treatable condition, is now proceeding.



FOREST PRODUCTS LABORATORIES OF CANADA.

Weight per cubic ft of Jack Pine containing various percentages of moisture.

Fig 2.

TABLE 3—Results obtained in the treatment of jack pine test pieces, using a half-hour pressure period.

Unit No.	Average Moisture Content (% of oven-dry wt)	[1]Absorption, per cu. ft.	Penetration (Heartwood.)
		lb.	
112a	42·0	12·2	Unsatisfactory ; erratic ; estimated average ¼ inch. (See plate 3.)
113a	38·9	11·4	
114a	36·2	13·4	
115a	39·0	7·8	
116a	26·8	12·5	
117a	33·6	11·6	
118a	26·6	9·8	
119a	45·0	8·1	
120a	59·6	9·7	
121a	38·9	10·7	
122a	36·9	11·0	
123a	32·1	7·9	
124a	29·5	8·6	
135a	46·2	9·3	
126a	43·6	8·7	
127a	41·4	8·8	
128a	32·0	11·7	
129a	32·2	8·1	
130a	38·5	10·0	
131a	34·7	9·2	
Average	37·7	10·0	

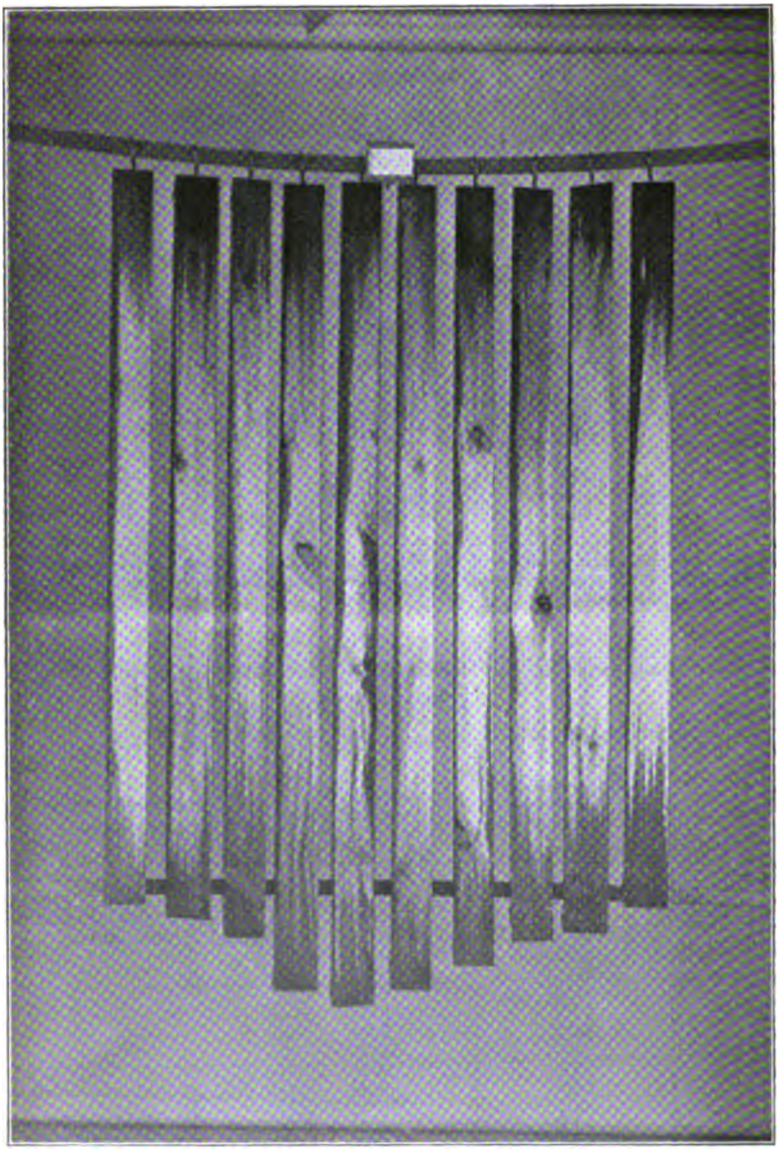
---

[1] Absorption per cubic foot in pieces of the size treated is, of course, higher than would occur in the same kind of timber of tie size treated by the same process. Penetration in the heartwood, however, would be the same in both cases.

TABLE 4—Results obtained in the treatment of jack pine test pieces, using a one-hour pressure period.

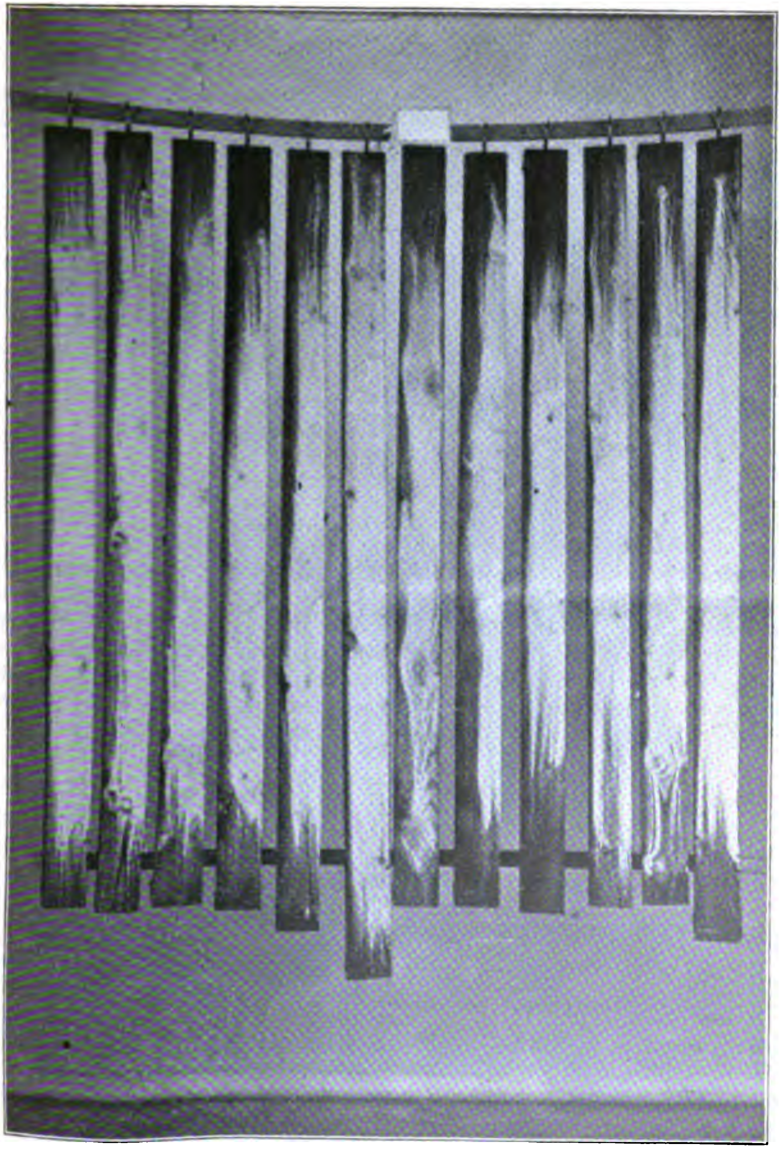
Unit No.	Average Moisture Content (% of oven-dry wt.)	Absorption per cu. ft.	Penetration (Heartwood).
		lb.	
132b	34·0	10·5	Unsatisfactory; erratic; estimated average ⅜ inch. (See plate 4.)
133b	30·5	10·1	
134b	32·2	10·0	
135b	31·5	9·1	
136b	41·0	6·5	
137b	42·2	9·3	
138b	44·1	7·5	
139b	29·5	12·7	
140b	32·0	9·3	
141b	34·8	8·4	
142b	36·7	10·4	
143b	52·6	6·8	
144b	43·1	9·3	
145b	25·0	11·5	
146b	33·1	10·0	
147b	26·7	11·5	
148b	38·0	13·2	
149b	36·2	8·6	
150b	38·7	9·0	
151b	41·2	10·0	
Average	36·1	9·7	

Plate III



Penetration obtained in jack pine heartwood using a half-hour pressure period (about one-twelfth actual size). See Table 3.

Plate IV



Penetration obtained in jack pine heartwood, using a 1-hour pressure period (about one-twelfth actual size). See Table 4.

TABLE 5.—Results obtained in the treatment of jack pine test pieces, using a two-hour pressure period.

Unit No.	Average Moisture Content (% of oven-dry wt.)	Absorption per cu. ft.	Penetration (Heartwood.)
		lb.	
132a	34·0	11·4	Fairly satisfactory; somewhat erratic; estimated average ⅝ inch. (See plate 5.)
133a	30·5	14·8	
134a	32·2	11·0	
135a	31·5	8·2	
136a	41·0	12·7	
137a	42·2	13·0	
138a	44·1	16·0	
139a	29·5	18·4	
140a	32·0	12·4	
141a	34·8	13·1	
142a	36·7	11·8	
143a	52·6	15·4	
144a	43·1	13·9	
145a	25·0	17·2	
146a	33·1	13·7	
147a	26·7	15·0	
148a	38·0	18·9	
149a	36·2	13·4	
150a	38·7	10·7	
151a	41·2	11·2	
Average	36·1	13·6	

Comparing the results stated in Tables 3, 4 and 5 it may be noted that, in material of approximately equal moisture content, satisfactory penetration was not secured with pressure periods of half an hour or one hour, but that with a two-hour period reasonably satisfactory penetration was obtained. It is concluded that jack pine, seasoned to about the stage indicated, can be satisfactorily creosoted under the conditions stated when a pressure period of not less than two hours is used. Further tests, in which other pressure periods were used, confirmed the above conclusion.

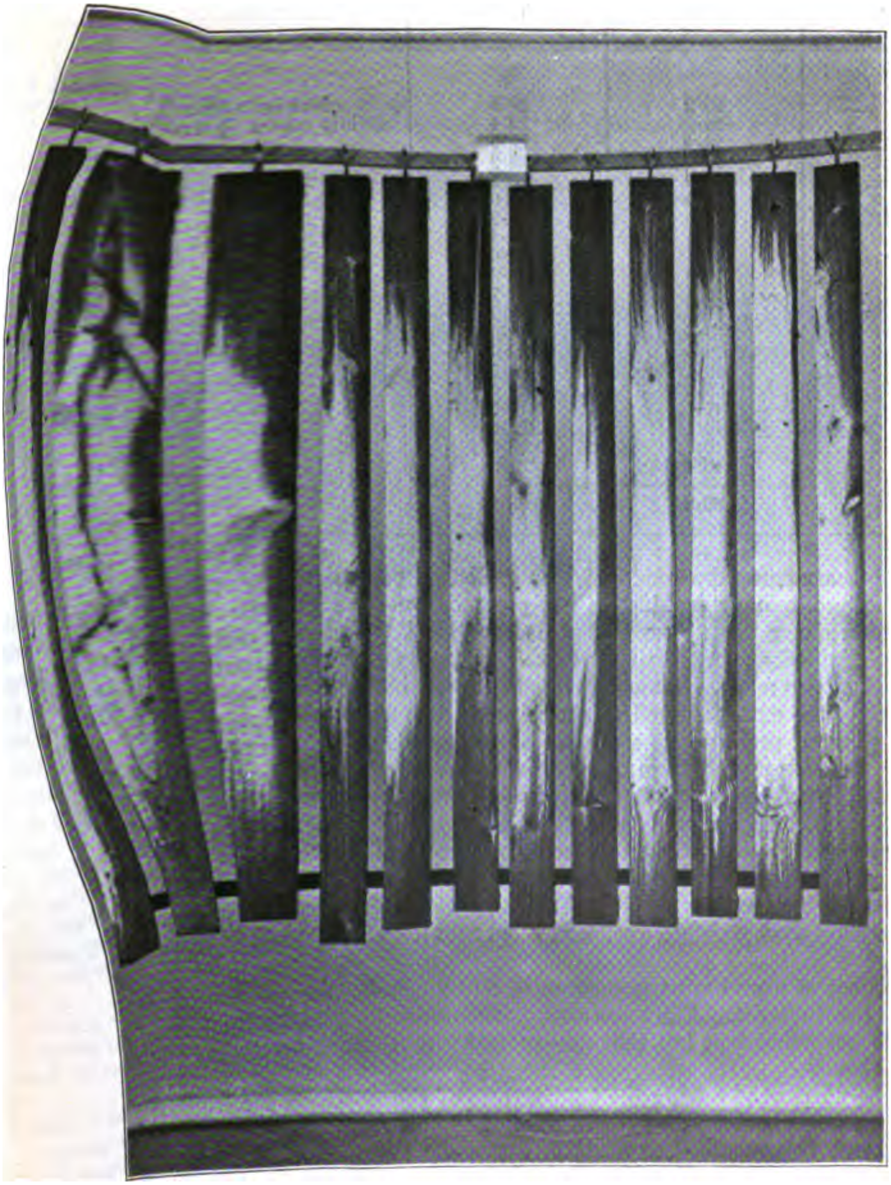
HEMLOCK

To ascertain the results obtainable in hemlock when creosoted by the usual methods a large number of charges, each consisting of about twenty test pieces, were treated by various processes in common commercial use. The penetration obtained was extremely poor and decidedly erratic except in occasional pieces in which individual peculiarities probably rendered the wood much more easily penetrable. The attempt was then made to secure satisfactory penetration by means of severe treatments in which pressure periods up to 12 hours, temperatures up to 225°F., and pressures up to 200 pounds per square inch were employed. These treatments considerably increased absorption per cubic foot but still failed to give a satisfactory penetration. The increased absorption was due mainly to greater end penetration. It was found that the test pieces were treated practically to refusal in less than 6 hours.

The employment of pressures exceeding 200 pounds per square inch is not feasible in the ordinary commercial plant, and it was concluded from the results that raising the temperature a further 25° or 50° F. would not appreciably increase penetration. It was therefore concluded that there was nothing to be gained by further tests along these lines.

Typical results obtained by treating for 6 hours at 225° F. and 200 pounds per square inch (maximum pressure being reached in 45 minutes), followed by a vacuum of 26 inches for 15 minutes, are shown in Table 6.

Plate V



Penetration obtained in jack pine heartwood using a 2-hour pressure period (about one-twelfth actual size). See Table 5.

TABLE 6.—Results obtained in the treatment of hemlock test pieces, using a six-hour pressure period.

Unit No.	Average Moisture Content. (% of oven-dry wt.)	Absorption per cu. ft.	Penetration (Heartwood).
		lb.	
56b	20·2	26·3	Quite unsatisfactory; estimated average slightly over ¼-inch.
57b	20·2	22·4	
58b	28·4	25·9	
59b	19·2	28·2	
60b	20·0	20·4	
61b	19·0	18·9	
62b	19·6	27·2	
63b	22·1	29·4	
64b	17·7	29·0	
65b	19·8	14·3	
66b	19·4	21·7	
67b	19·7	23·3	
68b	19·5	29·3	
69b	19·6	16·0	
70b	19·1	22·5	
71b	23·8	19·6	
72b	17·7	15·5	
73b	19·1	24·6	
74b	19·7	28·8	
75b	19·4	21·6	
Average	20·2	23·2	

Other treatments were tried in which prolonged preliminary steaming, preliminary vacuum, or preliminary soaking in hot preservative were resorted to. An extensive investigation along these lines still failed to yield the desired results, penetration remaining decidedly poor. In view of this fact it is unnecessary to go into all the details of the tests made. Some general statements in this connection however may be of interest. The material used was air-dry or approximately air-dry in all cases.

The effect of preliminary steaming at 20 pounds per square inch with saturated steam for periods ranging from two to twelve hours, followed by vacuum of 26 inches for one-half to two hours, was investigated. It was found that steaming at 20 pounds per square inch, even for two hours, retarded penetration of the preservative from the outer surfaces and apparently caused serious damage to the wood; that lengthening the steaming period appeared to cause increased damage and further retarded penetration. While steaming may render possible the securing of a satisfactory absorption per cubic foot, it appears that such absorption is secured only at the cost of serious damage to the wood.

The effect of a preliminary vacuum of 26 inches for periods ranging from one to five hours was investigated. It was found that preliminary vacuum tended to increase absorption per cubic foot but that any increase in penetration was so slight as to be inappreciable.

For the purpose of raising the temperature of the wood for some distance from the surface to a point sufficiently high to prevent the oil from congealing as it penetrated into the wood, treatments were made in which the test pieces were soaked in creosote oil at a temperature of 190° F. and at atmospheric pressure for several hours prior to applying higher pressure. This procedure failed to yield satisfactory results in regard to penetration.

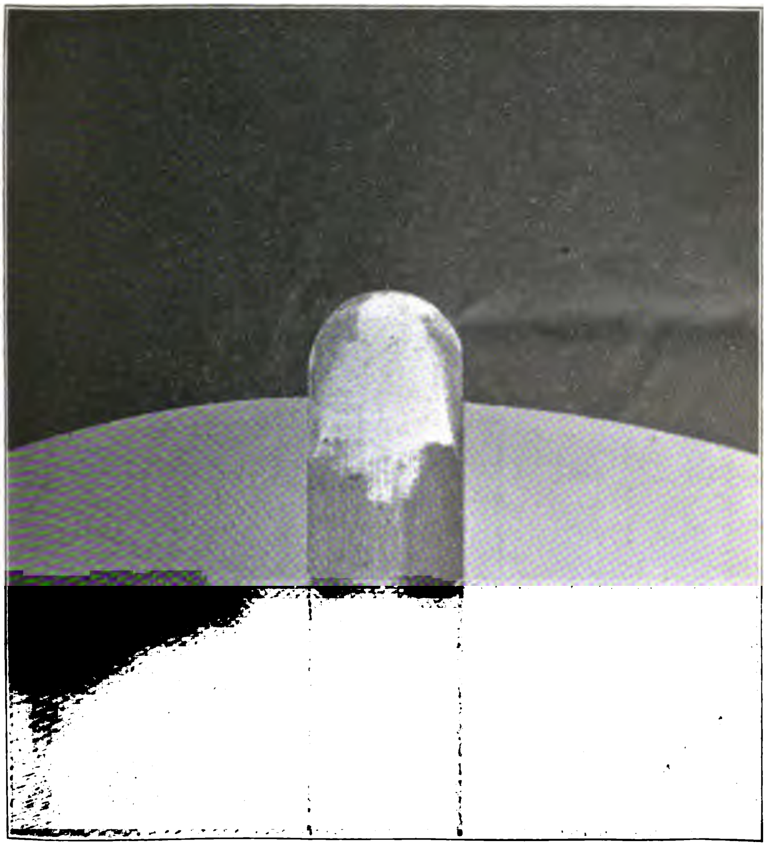
EXPERIMENTAL DATA, PART II

TREATMENT OF JACK PINE AND EASTERN HEMLOCK PREPARED BY SPECIAL METHOD

HEMLOCK

No satisfactory method of impregnating hemlock having been found, it was considered advisable at this point to approach the problem in an entirely different way. Trial was therefore made of the effect of making small holes in the surface of the timber before impregnation, with the idea of facilitating penetration and distribution of preservative. This principle, while it is a revolutionary one in wood preservation, is not entirely new. There is some doubt as to just where and when it originated. It is believed that the first developments worth mentioning in this connection occurred in Austria prior to 1911. The process was there used in the treatment of poles. Some developments along this line subsequently occurred both in Germany and on the Pacific coast of America and attention has also been occasionally drawn to the method in technical periodicals in recent years. Preliminary trials of the process in this investigation soon led to a recognition of its possibilities and attention was therefore concentrated on its development.

Plate VI



Side view of one of the knife-like projections used in the experimental incising machine (about actual size).

After a large number of tests with an experimental machine it was found that by far the best results were obtained by producing in the surfaces of the timber incisions of a special character by means of projections of a knife-like form in contradistinction to those of a circular, rectangular or other form in cross-section. (See Plate 6.) The incisions used were relatively long and very narrow and were so made that the disturbance to the fibres of the wood was very slight and so that the incisions closed up after treatment and were barely noticeable. (See Plate 7.) The arrangement or spacing of the incisions was found to be of great importance. Suitable arrangement permits of uniform distribution of the preservative throughout the treated zone in a relatively short period.

Plate VII

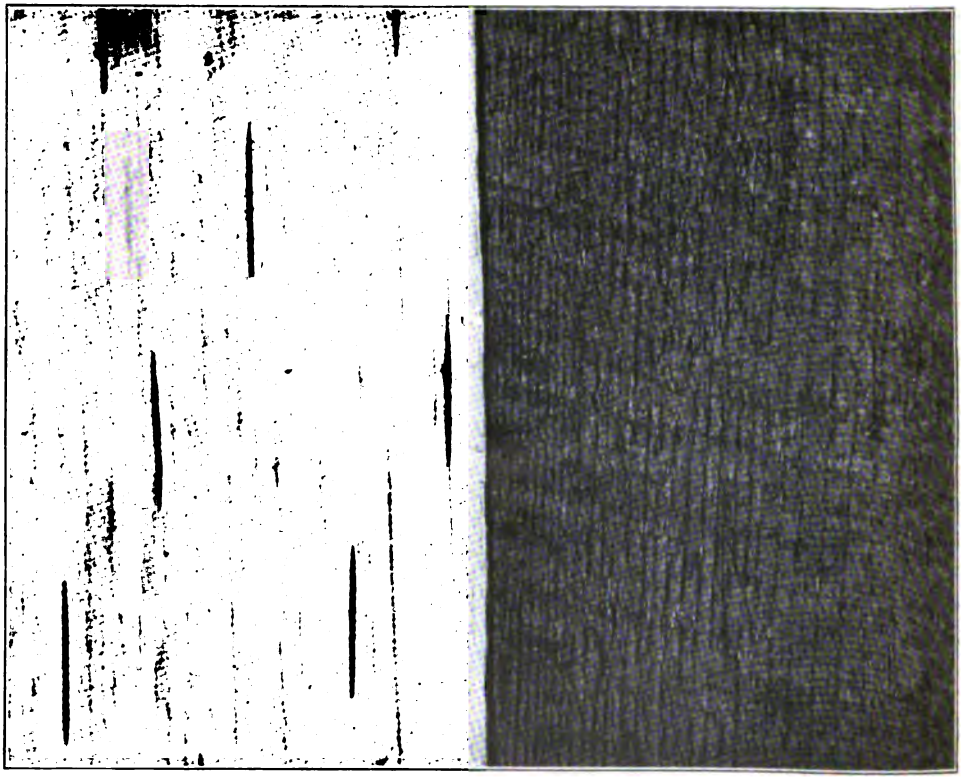


FIG. 1 FIG. 2

FIG. 1.—View showing incisions before treatment of the timber (actual size).
FIG. 2.—View showing incisions after treatment (actual size). The incisions have closed up so as to be difficult to distinguish.

These incisions, as distinct from round or other holes or perforations, present to the direct action of the preservative a much larger surface for penetration across than with the grain, thus somewhat compensating for the fact that wood is much more easily penetrable with than across the grain, and enabling a much more uniform distribution of preservative to be obtained than can usually be secured in ordinary practice. It was also found that by incising timber in this way every unit in a charge showed satisfactory penetration.

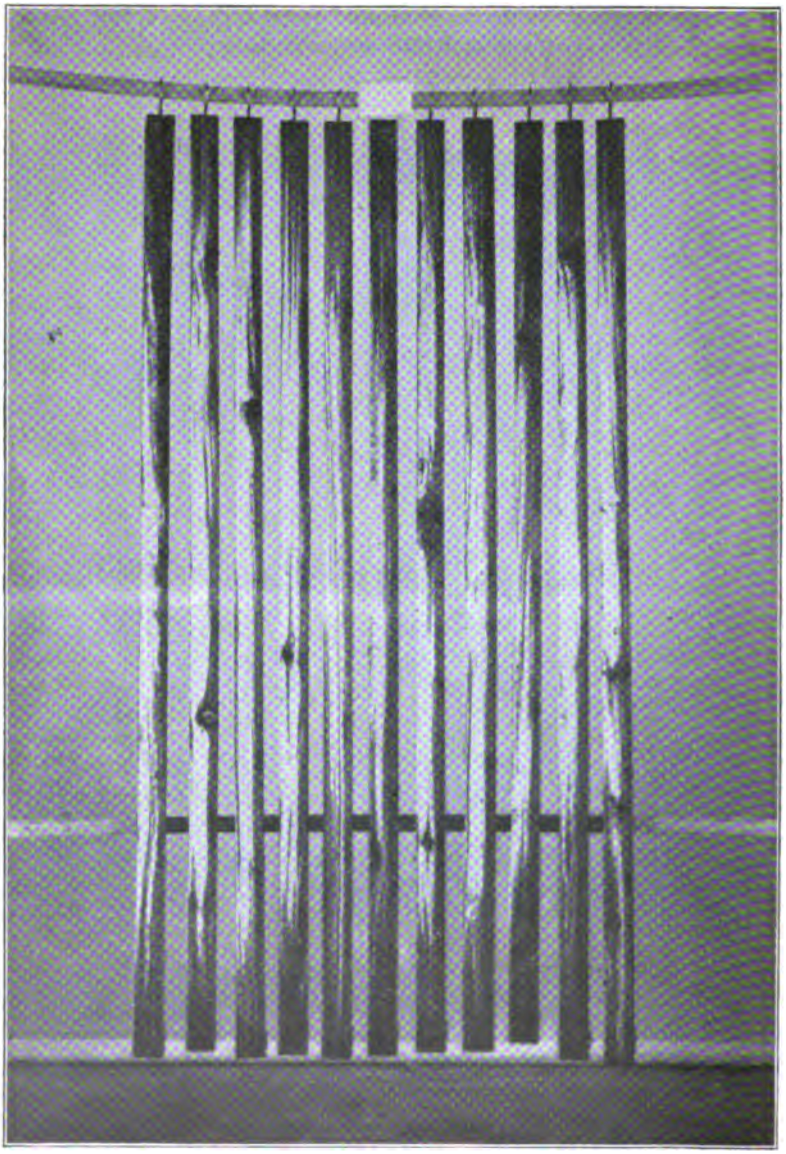
Tests made to determine the effect of incising on strength indicated that with the type and arrangement of projections used the reduction in strength was so slight as to be negligible.

A number of charges of hemlock were treated after incising. It was found that highly satisfactory penetration could be secured in air-dry material with a pressure period of about two hours' duration. Typical results obtained in the treatment of incised hemlock with an oil temperature of 185° F. and a pressure of 175 pounds per square inch (maximum being reached in 45 minutes) followed by a vacuum of 26 inches for 15 minutes, are shown in Table 7.

TABLE 7.—Results obtained in the treatment of incised hemlock test pieces, using a two-hour pressure period.

Unit No.	Moisture Content (% of oven-dry wt.)	Absorption per cu. ft.	Penetration (Heartwood).
		lb.	
95 b	19·2	14·6	Very uniform; estimated average ¾ inch. (See plate 8)
96 b	18·5	18·1	
97 b	20·4	18·0	
98 b	19·5	24·6	
99 b	17·5	20·8	
100 b	16·8	25·0	
101 b	18·2	13·4	
102 b	20·2	16·3	
103 b	20·4	24·8	
104 b	18·2	25·0	
105 b	18·8	15·5	
106 b	18·7	19·0	
107 b	20·0	14·8	
108 b	19·1	15·7	
109 b	19·2	16·2	
110 b	17·5	17·8	
111 b	17·5	22·4	
Average	18·8	18·9	

Plate VIII



Penetration obtained in incised hemlock heartwood, using a 2-hour pressure period (about one-twelfth actual size). See Table 7.

JACK PINE

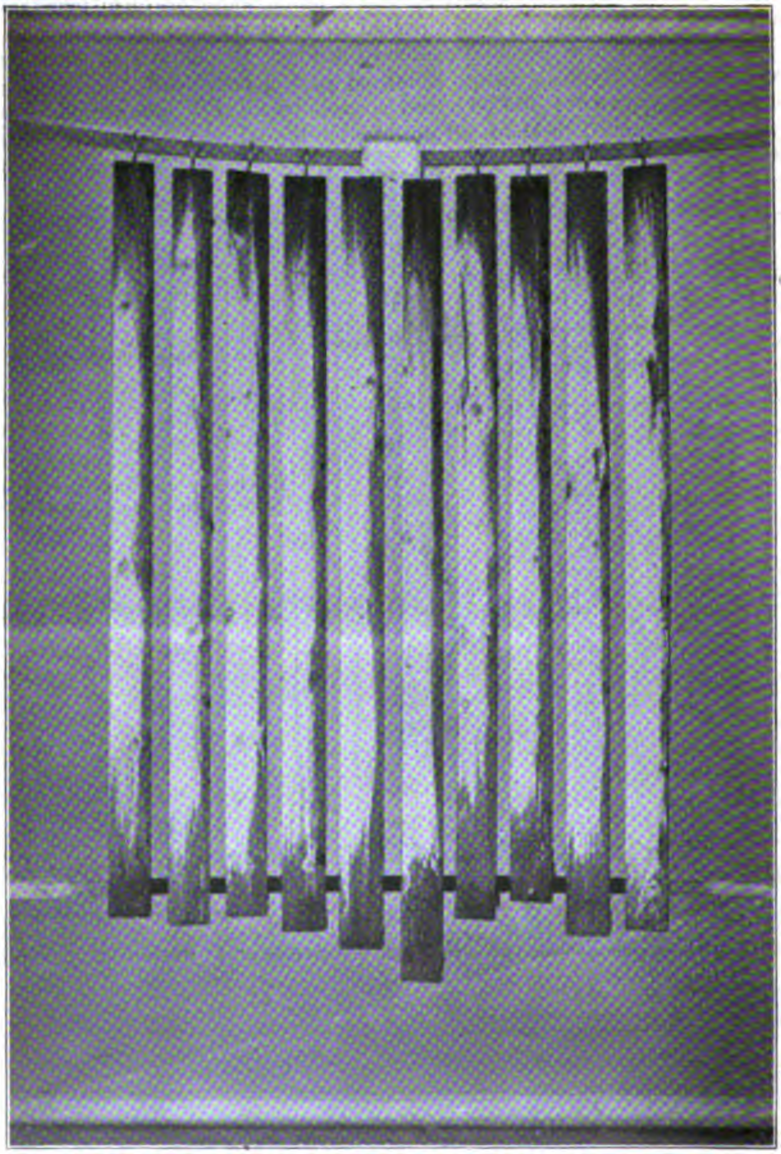
In view of the results described above on hemlock it was considered desirable to investigate the effect of incisions in the treatment of jack pine. After treating a number of charges consisting of incised test pieces it was found that with similar material in both cases a somewhat deeper and much more uniform penetration than was secured with a two-hour pressure period in wood without incisions was obtained with a half-hour pressure period in incised timber, the details of treatment being otherwise identical. Typical results obtained in the treatment of incised jack pine with an oil temperature of 185° F. and a pressure of 175 pounds per square inch (maximum being reached in about 40 minutes) followed by a vacuum of 26 inches for 15 minutes, are shown in Table 8.

TABLE 8.—Results obtained in the treatment of incised jack pine test pieces, using a half-hour pressure period.

Unit No.	Average Moisture Content (% of oven-dry wt.)	Absorption per cu. ft.	Penetration (Heartwood.)
		lb.	
112b	42·0	11·2	Excellent; very uniform; estimated average 7/8 inch. (See plate 3.)
113b	38·9	12·1	
114b	36.2	15·3	
115b	39·0	9·9	
116b	26·8	10·6	
117b	33·6	12·0	
118b	26·6	13 0	
119b	45·0	9·0	
120b	59·6	9·2	
121b	38·9	10·8	
122b	36·9	13·4	
123b	32·1	10·4	
124b	29·5	11·6	
125b	46·2	11·9	
126b	43·6	9·2	
127b	41·4	9·5	
128b	32·0	10·1	
129b	32·2	....	
130b	48·5	10·4	
131b	34·7	13·2	
Average	38·2	11·2	

The outstanding results of the investigation are briefly presented in Table 9.

Plate IX



Penetration obtained in incised jack pine heartwood, using a half-hour pressure period (about one-twelfth actual size). See Table 8.

TABLE 9.—Typical results obtained in treating Jack Pine and Eastern Hemlock with and without incisions.

Species.	*Dimensions of Test Pieces.	Number of Pieces per Charge.	Moisture Content (% of oven-dry weight).	†Details of Treatment.			Penetration (side.) — (Heartwood.)	‡Absorption per cu. ft.	Treatment in General.	Remarks.
				Temp. of Preservative	Pressure	Duration of Pressure Period.				
				°F	lb. per sq. in.	hrs.		lb.		
Hemlock........	4 in. x 5 in. x 5 ft	20	20·2	200	200	6	Extremely erratic; average ¼ in.	23·2	Quite unsatisfactory.	Not incised.
"	" "	20	18·8	185	175	2	Very uniform; average ¾ in.	18·8	Excellent.....	Incised.
Jack pine....	4 in. x 4 in. x 4 ft.	20	36·1	185	175	2	Somewhat erratic; average ⅜ in.	13·7	Fairly good...	Not incised.
"	" "	20	38·2	185	175	½	Very uniform; average ⅞ in.	11·2	Excellent.....	Incised.

* All test pieces free from defects and strictly heartwood, winter cut and similar (within the same species) as to rate of growth and condition of seasoning.

† In all cases maximum pressure was reached in 40-45 minutes and a final vacuum of 26 ins. was drawn for 15 minutes.

‡ The absorption per cubic foot in pieces of the size treated is, of course, much higher than would occur in sound timber of tie size treated by the same process. Penetration, however, would be the same in both cases.

The absorption per cubic foot in actual ties will be determined when the ties now being used in the seasoning study become available for treatment. (See footnote p. 9.)

CONCLUSIONS

(1) Satisfactory penetration of creosote oil can be secured in jack pine heartwood, even when not thoroughly air-dry, by several processes in common commercial use.

(2) By means of the incision method[1] satisfactory penetration can be secured in jack pine heartwood, even when not thoroughly air-dry, in a considerably shorter time and with less preservative per cubic foot than when treated unincised. Further, the penetration is much more uniform in the incised timber.

(3) It does not appear possible to secure a satisfactory penetration of creosote oil in eastern hemlock heartwood, even when air-dry, by processes in common commercial use.

(4) Air-dry eastern hemlock heartwood can be impregnated with creosote oil in a thoroughly satisfactory and economical manner by means of the incision method.

(5) Incising timber causes a slight reduction in its strength. This reduction, however, is so slight as to be negligible for all practical purposes and is amply justified on account of the better protection given to the timber, in treatment, as a result of incising.

(6) A thorough trial of the incision method on a commercial scale is desirable, especially as results similar to those reported above could almost without doubt be secured in a number of other species in addition to jack pine and eastern hemlock.

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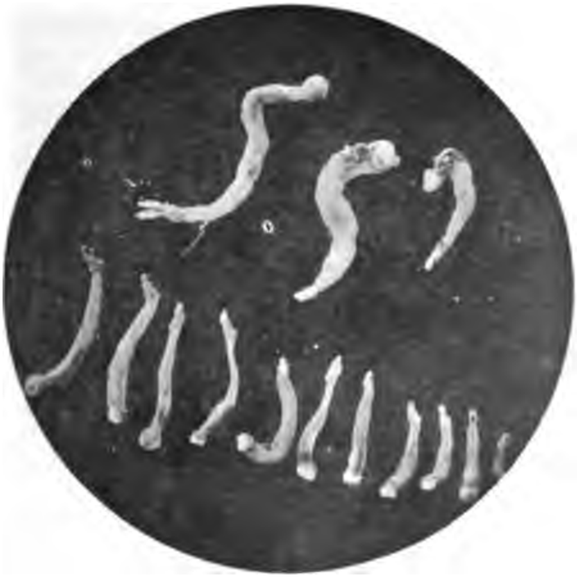
[1] Patents applied for.

CIRCULAR 139 6

The European Pileworm

A Dangerous Marine Borer in Barnegat Bay New Jersey



MARINE BORING MOLLUSCS
Native species (above); European pileworm (below).

NEW JERSEY
AGRICULTURAL EXPERIMENT STATIONS

NEW BRUNSWICK, N. J.
March 1, 1922

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The European Pileworm

A Dangerous Marine Borer in Barnegat Bay, New Jersey

by

THURLOW C. NELSON, Ph.D.

March 1, 1922

Most of us think of clams, oysters, and other bivalve molluscs as animals excellent to eat, and hence as of great value to man. So indeed they are, but just as among some other groups of animals which are mainly beneficial, so among the bivalve molluscs there are a few dangerous pests. The so-called "shipworms," marine boring molluscs, have been known for centuries. These curious animals are not worms, as many people believe, but bivalve molluscs closely related to the common clams. The necessity for protecting the bottoms of sea-going vessels from their attacks has long been recognized.

Destruction by the Pileworm

Until recently the attacks by marine borers upon wooden structures in this state have been confined to those of the relatively slow-growing native species, *Bankia fimbriata* (*Xylotrya fimbriata*, Jeffries), which has done comparatively slight damage. During the past summer, however, there appeared in Barnegat Bay, N. J., the European pileworm, *Teredo navalis*,[1] a pest which for centuries has literally ravaged the coasts of Holland, England, and Scandinavia, destroying dikes and other marine structures with great rapidity. A short time ago this mollusc was in some manner introduced into San Francisco Bay, California, where in the last two years it has extensively destroyed piling and other marine structures entailing a loss of millions of dollars. To show something of the rapidity with which *Teredo navalis* multiplies, and the swiftness with which great marine structures are literally wiped out by its activities, a brief history of its work in San Francisco Bay will be instructive.

From the Report on the San Francisco Bay Marine Piling Survey for 1921 (3), we learn that the European pileworm was first discovered in San Francisco Bay in 1914 by A. L. Barrows. For the next five years it did little damage, but suddenly, in 1920, coincident with a period of unusually low rainfall, the attacks of this mollusc became widespread over a large part of San Francisco Bay. Before owners were aware that anything was wrong, the borers had completely cut off at the mudline the piling of many piers, terminals, and other marine structures (fig. 1). Based upon the costs of repairs and replacements made necessary through these attacks, a careful estimate of the damage done during 1920 and 1921 in San Francisco waters alone gives a figure in excess of $15,000,000.

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[1] Some doubt has been expressed as to whether this form is really *Teredo navalis*, of European waters, or is some native species of *Teredo*. Our material has been sent to Mr. W. F. Clapp, of Harvard University; to Dr. W. T. Calman, of the British Museum of Natural History, and to Dr. Ed. Lamy, Museum D'Historie Naturelle, Paris. The identification given in each case was *Teredo navalis*, L. Dr. Calman writes that our specimens "do not differ more from the specimens labelled *T. navalis* in our collection than the latter do from one another." The writer wishes to express his thanks to each of these gentlemen for making the identifications.

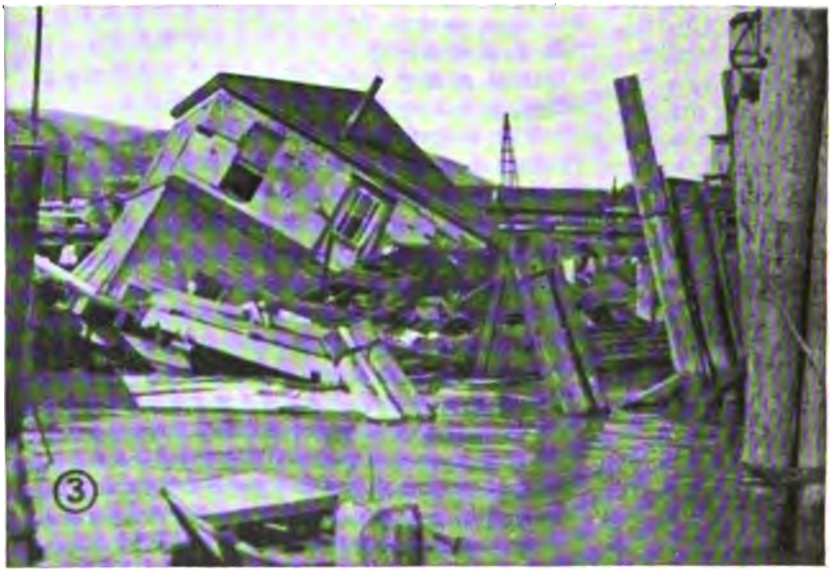

FIG. 1. MUNICIPAL WHARF AND HOUSE, BENICIA, CALIFORNIA
Collapsed October 7, 1920. (Reproduced by courtesy of San Francisco Marine Piling Committee from their report, 1921, pl. 1, fig. 3.)

The two most important reasons why the European pileworm is so much more dangerous than the native species are: first, that it invades the brackish water area and comes much closer to fresh water than do other borers; and second, that it requires but a very short time to reach sexual maturity, and in a single season produces enormous numbers of young.

What it is and How it Lives

Before describing the outbreak of *Teredo navalis* in Barnegat Bay last summer, let us consider briefly some of the most important points in the make-up and the life history of the animals. The figure on the title page shows a number of young specimens of *Teredo navalis,* sexually mature, as removed from their burrows. Three specimens of the native shipworm, *Bankia fimbriata,* are shown above for comparison. Note the two delicate shells which partly cover the front or anterior end, and between which lies the foot (fig. 5). By far the greatest part of the animal is naked, and since it cannot pull its entire body within its shell as does the ordinary clam, it finds protection in its burrow from the attacks of fish and other enemies. Just imagine a soft clam (long-necked clam), in which the neck, or siphons and the soft part of the body were from ten to twenty times as long as the shell, and you will have an animal which closely resembles the pileworm.

As it bores its way into the wood, the pileworm excavates for itself a burrow, which opens to the outside through a small pore not larger than a pinhole (fig. 3). Through this small opening it projects two small tubes, or siphons, the lower (ventral) one being the longer, the upper (dorsal) one much shorter. By means of millions of microscopic hair-like structures, known as cilia, which are beating in one direction, a current of water is drawn in through the lower, or incurrent, siphon, and expelled through the upper, or excurrent, siphon. The water in its course through the body passes through the gills, as it does in other bivalve molluscs. Here it gives up oxygen to the blood, while all food materials are filtered out and carried to the mouth. For like its relatives, the clam and the oyster, the marine borer lives mainly upon the very small microscopic animals and plants in the water. It is still an open question whether the borers may derive some nutriment from the wood which is shaved off in making the burrow, but it should be emphasized that the marine boring molluscs enter the bottom of your boat, or the piling of your wharf, not primarily because the wood is food for them, as it is for the wood-boring insects on land, but because the wood furnishes them with a safe retreat where the soft parts of the body are protected.[2]

Pileworm Repels Invaders

The common soft clam buries itself in the sand, leaving only a small hole above it through which its siphons are pushed up to the water. In much the same way the marine boring molluscs depend upon the very small opening through which they entered the wood for keeping in touch with the outside world. But just here the marine borer goes the clam one better. Those of us who have dug soft clams have seen the long red sand worms or clam worms, which crawl down the hole made by the siphons of the clam, and devour the luckless bivalve at the bottom. No such thing can happen to the pileworm, however, for like many troublesome pests it has developed means of repelling invaders. On either side of the siphons is a spade-like structure, made of lime, which bears two sharp points on its outer edge (fig. 2). These structures, known as pallets, are attached to muscles by which they may be forced together into the hole at the end of the burrow (fig. 3) or

---

[2] Harington (2) finds that the larvæ of *Teredo norvegica* are strongly attracted to an alcoholic or an ethereal extract of sawdust, and also to a 1 per cent solution of malic acid. He finds a slight hydrolysis of cellulose by enzymes extracted from the digestive gland of *Teredo*, indicating that at least during the period of growth and burrow enlargement the pileworm may derive some nutriment from the wood.

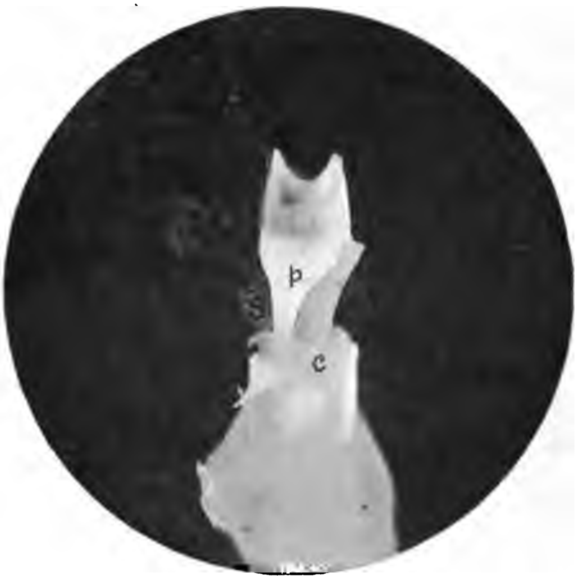

Fig. 2. Posterior, or Hind End of Teredo navalis
c, collar; p, pallet; s, pigmented siphons

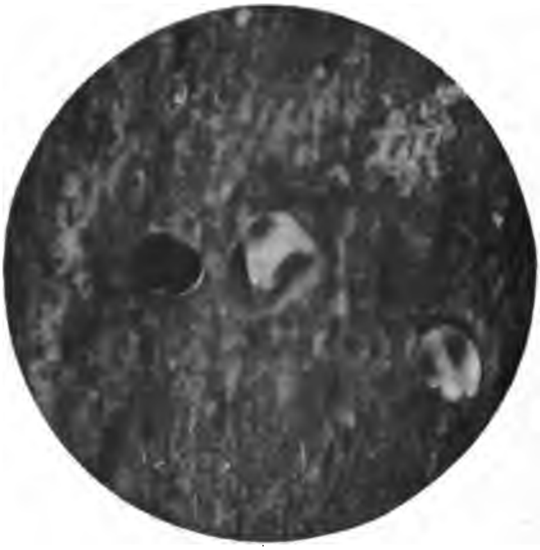

Fig. 3. Protruding Pallets of Teredo navalis
and empty burrow of a third, as they appear on the surface of the wood

withdrawn when the animal extends its siphons to take in water for food or oxygen. Let a worm or other enemy attempt to enter the hole, and instantly the siphons are withdrawn and the pallets thrust out, blocking the entrance.[3] In our native species, *Bankia fimbriata,* the pallets are beautiful feather-like structures of purest white (fig. 4). Anyone may determine, without the aid of a lens, whether he is dealing with *Teredo* or *Bankia,* by examination of these pallets.

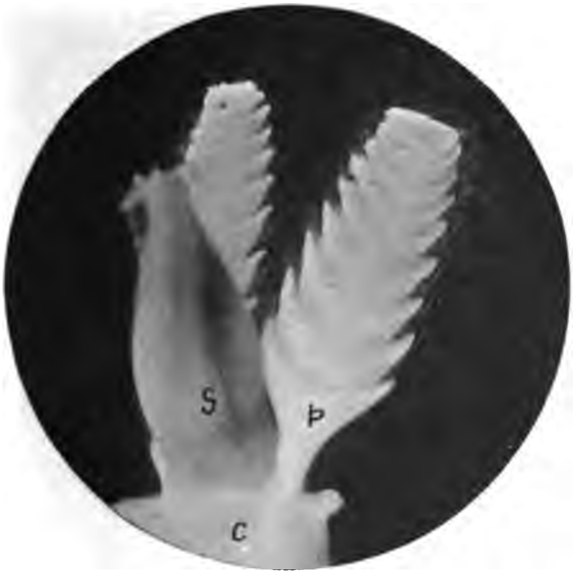

FIG. 4. POSTERIOR END OF BANKIA FIMBRIATA, THE NATIVE SPECIES
c, collar; p, pallet; s, non-pigmented siphons

Bores with its Shell

You may wonder why, since the animal lies completely within a burrow, it has kept any shells at all. Here we see a strange instance of how in nature a structure which originally is developed entirely for protection, as it is in the clams and oysters, becomes by slight changes adapted to quite different ends. For the shell of the pileworm is not used as a protective covering but is the tool by means of which it bores.

The shells of the hard clam, and those of most bivalves, are joined together by a long hinge on the upper, or dorsal, side, and fit together evenly all the way around. In the pileworm and its allies the shells meet only at two narrow points; in the hinge region, and directly opposite on the lower side, where each shell bears a rounded knob. On account of the great development of these knobs the front and back edges of the shells are pushed far apart and never touch as they do in the clam (fig. 5).

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[3] Calman (1) notes that a species of annelid worm, *Nereilepas fucata,* has been stated to prey on *Teredo navalis,* but there is no evidence that its attacks lessen to any appreciable extent the destruction wrought by the pileworm.

Everyone who has seen a clam on the half shell has noticed the two rounded pinkish white adductor muscles, one in front and one behind, by which the shells are closed. In the pileworm these muscles do not work together as they do in the clam, but alternately, so that the shells instead of opening and closing as do those of the clam, rock backward and forward on the knobs where they are in contact with each other. The muscle at the hinder end is much stronger than that in front, and has a greater leverage. so that it is able to exert a considerable force.

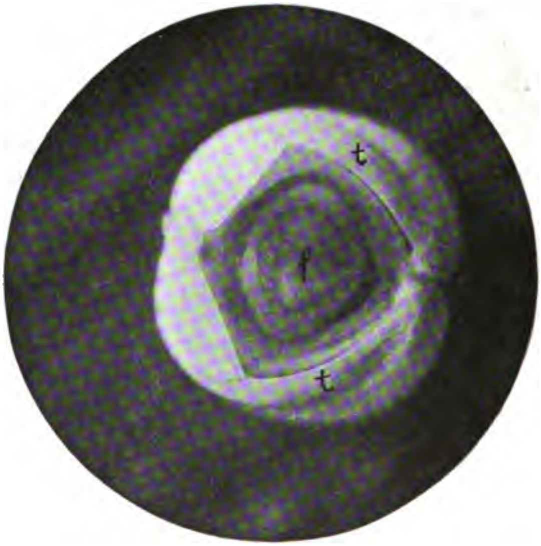

FIG. 5. ANTERIOR, OR FRONT END OF TEREDO NAVALIS SHOWING SHELLS ENCLOSING THE CIRCULAR FOOT

f, foot; t, the rows of rasping teeth which are carried on the front edge of the two shells

How Burrows are Made

The outer front surfaces of the shells bear several rows of rasping teeth which point backward (*t*, fig. 5). Consequently, when the hinder adductor muscle contracts, the front edges of the shell are sprung apart with such force that the teeth scrape off little shavings of the wood. The foot, which is circular and hollowed out, acts as a sucker and keeps the front edges of the shells, which bear the teeth, tightly against the end of the burrow while the animal is boring (fig. 5). As the mollusc grows it rasps away more and more of the wood, lengthening and enlarging the burrow. The shavings pass through the digestive tract, where they are held for some time, and then cast to the outside through the excurrent siphon.

As its burrow is extended the pileworm lines the walls with a thin layer of white shell which acts as a further protective covering for the animal, and also prevents any injury to the soft part of the body through contact with splinters of wood. The burrows of older borers are quite heavily lined with smooth white shell. It is an interesting fact that no matter how closely the marine borers may be crowded together, their burrows never run into each other, though the walls of wood separating them may be thin as tissue paper (fig. 6).

Pileworm Breeds Rapidly

An astonishing fact in the life of the pileworm is the rapidity with which it becomes sexually mature and begins to breed. The oyster in New Jersey does not usually breed until it is 2 years old, while clams require from 1 to 2 years to reach breeding age. As compared with this, Potts (6) found at Samoa, in the Pacific Ocean, with temperatures of the water ranging from 80 to 86° F., that *Teredo navalis* became sexually mature within 24 days of the time it entered the wood. The shallow coastal waters of this state are often warmed to 80° F. and above, during the summer, so that growth almost as rapid may occur here.

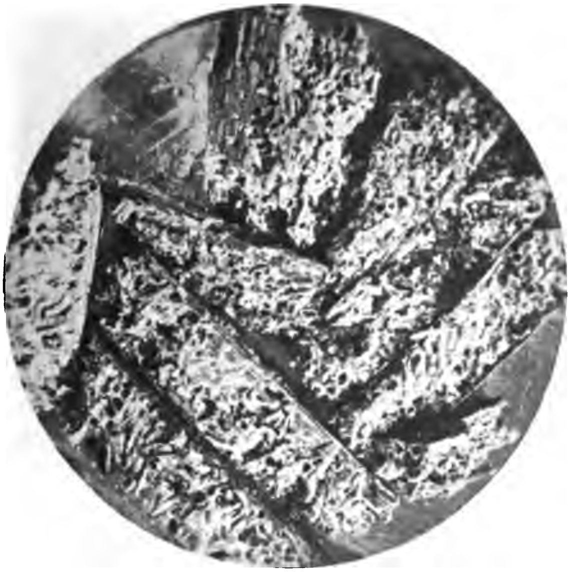

FIG. 6. PIECES OF CYPRESS FROM PLATFORM RIDDLED BY THE BURROWS OF TEREDO NAVALIS
Note the white shell which lines the burrows

In Barnegat Bay, N. J., breeding teredos have been found in less than 6 weeks from the time they attached themselves to the wood, and when they averaged only 3/5 inch in length. In *Teredo navalis* the eggs are fertilized within the gills of the female by spermatozoa thrown out through the excurrent siphon of a nearby male, and entering with the stream of water passing into the incurrent siphon of the female. Curiously enough there is only one male to about every 500 females.

Within the gills of the female many thousands and even millions of eggs develop into very small larvae looking much like those of the clam or of the oyster (fig. 7). (Compare with figures 5 to 11 in reference 5.) They have a pair of thin transparent shells of lime joined together by a straight hinge, the whole animal resembling a purse. Between the shells the ciliated swimming organ, the velum, is pushed out. After the larvae are cast out into the water through the excurrent siphon of the parent they swim actively about with the aid of the velum while carried to and fro by currents.

FIG. 7. LARVAE OF TEREDO NAVALIS TAKEN FROM THE GILLS OF THE PARENT
These larvae are ready to be thrown out into the water. Note the swimming organ, the velum, which projects from between the shells

It is not known just how long the larva of *Teredo* remains free-swimming in the water, but it is believed to be about one month in San Francisco Bay. In the warmer waters of this state the time is probably somewhat shorter. During the free-swimming period the larva grows to be about 1/100 inch long, or about five times the length it was when it left the parent. It then settles down on the surface of unprotected wood and attaches by means of a sticky thread, the byssus, which it spins out of the base of its foot. Then occurs a series of changes too complex to consider here, by which the velum is lost, and after the shells are modified for boring, the little pileworm enters the wood. When sexually mature it begins giving off larvae as did its parent. Since one teredo liberates from 500,000 to 1,000,000 larvae in a season, it is easy to understand how from one piece of infected wood an entire harbor might become infested with borers. Luckily for us the great majority of marine borers die before spring of each year, so that only a few live over to propagate the species.

Teredo navalis in Barnegat Bay

During the course of oyster investigations carried on in Barnegat Bay last summer, the writer came accidentally upon a heavy invasion of *Teredo navalis*. On July 3 a platform of cypress shingling lath, 3 by 6 feet, was covered with clean oyster shells and sunk on the northwest line of the Sloop Creek natural bed, some 2½ miles southeast of Barnegat Pier. The platform stood on legs which raised it about 8 inches off the bottom in 6 feet of water. On July 25 the platform was raised and taken into the tidal creek south of Potter's Creek, Bayville, N. J. Here it remained suspended from the laboratory houseboat, just beneath the surface of the water, until August 15, when it collapsed. Upon examination it was found to have been completely riddled by *Teredo navalis* (fig. 6 and 8). The pileworms, which averaged about 3/5 inch in length, were so closely crowded together that a single piece of lath, 1 by 2 inches, in a swath 2/5 inch wide around the lath showed 77 pairs of protruding pallets. The majority contained larvae ready to throw out. *Teredo navalis* becomes full grown by autumn of the season in which it attaches to the wood, reaching a length of about 8 inches. Of the native species, *Bankia*

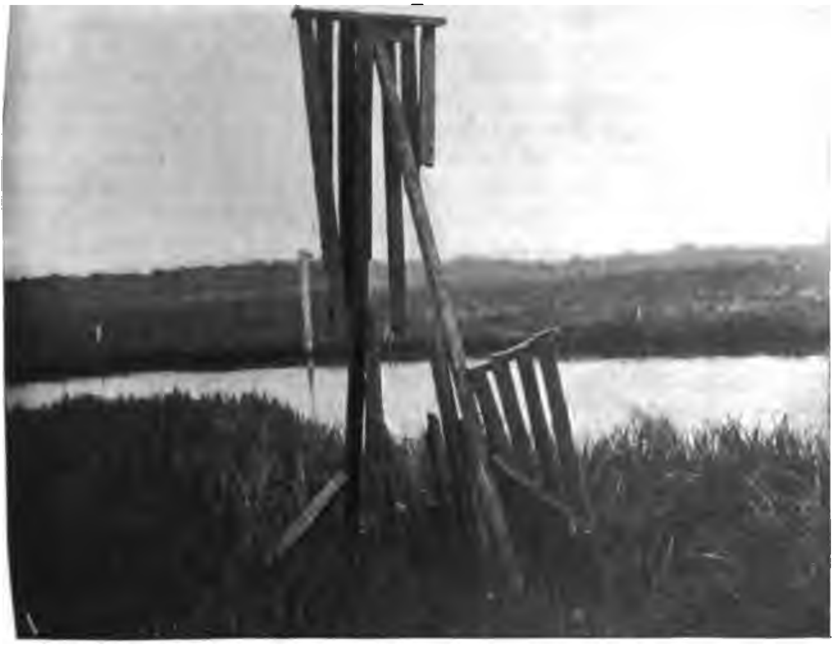

FIG. 8. CYPRESS PLATFORM WHICH COLLAPSED IN LESS THAN SIX WEEKS AFTER IT WAS PUT OVERBOARD IN BARNEGAT BAY

gouldi, a close relative of *Bankia fimbriata,* according to Sigerfoos (7) becomes full grown in about a year in California waters, at which time it may attain a length of 2 feet.

The exact date when the larvae of *Teredo* became attached to the platform is unknown, but as it must have occurred soon after July 3, it is probable that the growth of the pileworms to sexual maturity, with incidentally the complete destruction of the platform, must have occurred in about 5 weeks.

One reason for the very heavy infection of the platform by borers was the unusually high density of the water. From the reports of the United States Weather Bureau for New Jersey we find that the year 1921 was one of the five driest on record. The rainfall for the state as a whole was 8.08 inches below the normal, and for the seacoast area, 10.6 inches below the normal. During these 22 days in July when the platform was in Barnegat Bay, the water at the bottom near the platform ranged in salinity from 10,125 to 10,170, with an average of 10,145 (fresh or distilled water being 10,000), This is from 40 to 60 parts per 10,000 higher than would be found here in normal years. The average temperature of the water at the bottom during this period was 78° F., with a maximum of 80° and a minimum of 76°. During the period the platform was in the creek, the maximum density observed was 10,125, and the minimum 10,090. The maximum temperature during the same period was 87°, and the minimum 70°.

A remarkable feature of the higher salinity of last year, and one which should receive full recognition by engineers, is that during the summer water of relatively high salinity crept upstream along the bottom far above its normal limits. For example, on July 8 water samples taken in Toms River, just below the last boathouse in the town of Toms River, showed a salinity of 10,040 at the surface, while at the bottom, 6 feet, it was 10,095. The bottom sample contained numerous clam and oyster larvae which had worked at least 3 miles up the river from the nearest beds. The larvae of *Teredo* were not found at this time, but the salinity of the water was such that had they settled on the piling of the water front of the town of Toms River, they would have been able to develop into mature pileworms.

A Situation Dangerous to Oyster Shippers and Wharf Owners

Little fear is felt ordinarily of the attacks of marine borers in the bottoms of vessels which return every few days or oftener to a harbor in fresh water. The native shipworms, *Bankia fimbriata,* probably do not live in waters the density of which falls much below 1010 for any long periods.[4]

In contrast to this, however, according to the experience in San

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[4] A platform similar to the one sunk in Barnegat Bay was put out in the tidal creek some 50 feet below the laboratory houseboat on May 23. When examined on August 15 it was found to be slightly infected with *Bankia fimbriata.* The salinity of the water during this entire period, deduced from records which were taken twice daily, varied from 1006 to 1012, averaging about 1010.

Francisco Bay, the European pileworm may survive for long periods and do great destruction where the salinity of the water at no time rises above 1006 (4, p. 74). It makes little difference if the water becomes absolutely fresh at each low tide; the teredo merely pulls in its siphons and, plugging the opening into its burrow with the pallets, it awaits the more salty water coming in with the flood tide before beginning again to feed. According to Dr. Kofoid, *Teredo navalis* in pieces of wood lived for 8 days in running fresh water in San Francisco.

The salinity of the water at many points in New Jersey from which oysters are shipped is sufficiently high to permit the pileworm to do untold damage. Should it once gain a foothold at the mouth of Maurice River, for instance, the vast system of wharves, piling and oyster floats might be wiped out in a single season.

This is not a fanciful dream. This very catastrophe visited the Southern Pacific Railroad Terminal in San Francisco Bay. Three piles were drawn for examination in June, 1921, and showed no Teredo; in August the entire structure, worth several millions of dollars floated downstream, the piling cut off at the mudline by Teredo navalis.

The salinity of the water at the mouth of Maurice River is well above that capable of supporting the life of *Teredo navalis,* in fact it is of such a salinity that oysters set and grow to maturity for some distance up the river above the point where the wharves are located.

It cannot be urged too strongly that the Central Railroad of New Jersey and the Pennsylvania Railroad should draw some of the piling at Maurice River and at Bivalve and conduct a thorough examination. Let the pileworm once gain a foothold and the great extent of piling wharves, and oyster floats will be threatened with destruction. What has just been said of the mouth of Maurice River applies equally as well to all similar regions where unprotected piling occurs.

The teredo attacks most heavily just above the mudline, partly because the water here is of higher salinity than that at the surface and possibly also for other reasons. Any inspection, to be of value, therefore must be conducted by a diver, or better yet, piling should be pulled and sawn into 2-foot sections for examination.

Means of Protection

Since an ounce of prevention is always worth a pound of cure, it behooves all dock owners, marine engineers, shipping men, fishermen, and oyster growers to be on the alert for the first signs of invasion by the European pileworm. Any infested wood should be removed immediately, and old vessels, discarded wharfing, and other abandoned wooden structures should be carried away to avoid a possible source of infection of nearby structures. One infested piling is a menace to all others in the neighborhood. If you find wood infested with borers get in touch at once with Mr. R. T. Betts, Chief Engineer, Robbins-Ripley Co., 50 Church Street, New York City, who is Chairman of the National Committee on Marine Borer Investigations, or inform the writer at Rutgers College, New Brunswick, N. J.

Our knowledge of protective coverings is relatively slight. Copper paint as used on the bottom of vessels is of little use for piling, as it soon rubs off. Thoroughly creosoted piling stood up fairly well in San Francisco Bay during the recent invasion, though it must be emphasized that even in the wharves having the best records, standing entirely on creosoted piling, as high as 30 per cent of the piles showed more or less infection by the teredo. Any knot or bolt hole, or any deep scar formed in handling the piling, gives opportunity for the borers to enter. The storage and after-treatment of piling should be attended to with as much care as the actual creosoting; this is well set forth in the report of the San Francisco Committee (4).

Finally, it must be remembered that there are creosotes and creosotes—some good, others very poor. Based upon their experience in San Francisco Bay the San Francisco Committee has formulated specifications covering the grades of creosote to be used and the methods to be followed by the creosoting companies. These specifications are to be found in the report of the Committee (4).

Recommendations

The heavy invasion of the cypress platform by *Teredo navalis* as described in this circular, shows that somewhere in Barnegat Bay there must be infected wood. The menace of this to unprotected woodwork in the bay cannot be too strongly emphasized. It is recommended, therefore, that immediate inspection be made of the following structures in Barnegat Bay:

1. The public dock at Seaside Park.
2. Private and public wharves at Berkeley.
3. Traffic bridge from Island Heights to Berkeley (very important).
4. Pennsylvania Railroad bridge crossing Toms River at Island Heights.
5. Falkenberg's wharf, Barnegat Pier.
6. Pennsylvania Railroad bridge crossing Barnegat Bay from Toms River to Seaside Park. (In response to a letter to the Division Engineer, Trenton, N. J., informing him of the destruction of the platform by *Teredo navalis* as herein described, a visual inspection was made of the bridge on November 16, 1921. It was reported that only a few of the piles showed signs of the work of borers).

It would be most advisable in the last mentioned case to draw such piles as show any signs whatever of the presence of *Teredo*. All the piles in the bridge are creosoted, but if the experience in San Francisco Bay means anything to us, even treated piling is not to be considered immune from attack.

Remember that all our old ideas regarding the nearness to fresh water to which borers will come must be given up. We are not dealing with the native shipworms, but with a foreign enemy, having habits very different from those of our native species.

Let us not wait until lives are lost next summer as a bridge or wharf collapses with a holiday crowd, but let the inspection as above outlined BEGIN AT ONCE.

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AGRICULTURAL EXPERIMENT STATION

Department of Entomology

STUDIES IN TERMITE CONTROL

By W. C. O'KANE and W. A. OSGOOD

NEW HAMPSHIRE COLLEGE
OF
AGRICULTURE AND THE MECHANIC ARTS
DURHAM, N. H.

STUDIES IN TERMITE CONTROL

By W. C. O'Kane and W. A. Osgood.

SUMMARY

Termites are a destructive group of insects which attack and seriously damage beams, timbers, flooring, partitions and various products made of vegetable fibre.

The infestation here described took place in a modern hospital in a New Hampshire city and involved extensive damage to partitions, floors, beams and other woodwork.

A large amount of infested material was removed and destroyed. Tile and cement were substituted.

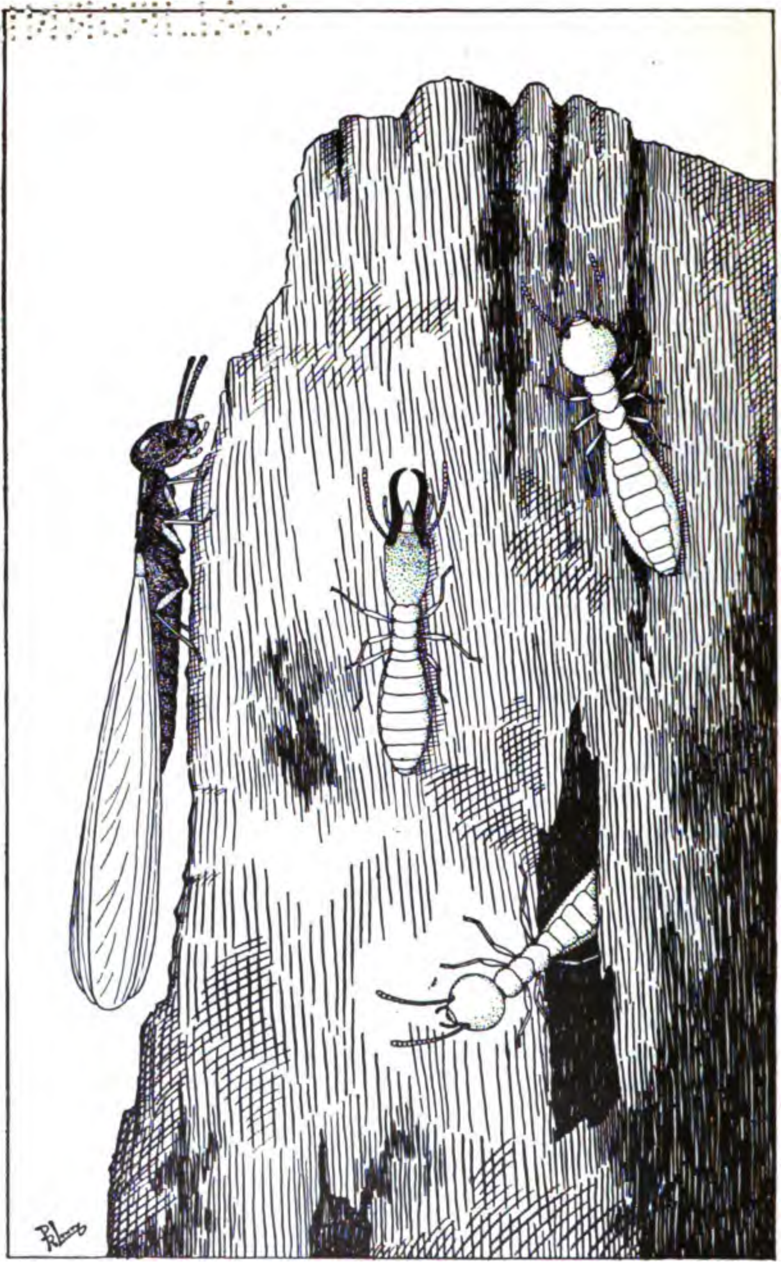
Preliminary experiments were arranged to determine the time and temperature factors necessary to kill termites in wooden beams by heat.

Supplementary steam piping was installed in the basement and the temperature was raised to 135° for 24 hours.

No living termites have since been discovered within the building.

The structure remained in undisturbed use for hospital purposes while the heat treatment was going on.

Extensive infestation was found through much of the hospital grounds. Board traps were utilized to discover the extent of this infestation. Timbers, board walk, apple trees, etc. were removed. A mixture of Phinotas oil and water at a dilution of one-half of one percent was used to kill termites in the ground and to render the ground unacceptable to them.



TERMITES AT WORK

(Enlarged to Ten Times Natural Size)

At the left is a winged migrant. In the center is a soldier with strong jaws for fighting. At the right is a worker. Emerging from a burrow is another worker.

INTRODUCTION.

Termites are a destructive group of insects which attack beams, foundation timbers, flooring, wood partitions and in fact all sorts of wood products to which they can gain access. They have a record of serious damage at various points in New Hampshire, and their work is of such a nature that in the majority of cases it is not discovered until a building is moved or torn down, or until repairs are instituted. Even then the damage is frequently ascribed to "dry rot."

In the tropics there are many species of termites but in New Hampshire, so far as is known, only one species is found, *Leucotermes flavipes* Koller. In the southern half of New Hampshire this insect is known to have caused serious damage in public buildings, farm houses, barns and other structures.

A familiar name for termites is "white ants." They are not really ants but they resemble them strongly in their superficial characters and, in addition, they have a community life which is similar in many respects to those of some of our common species of true ants.

Unlike ants, however, the great majority of termites are white in color, are sensitive to light, which they shun, and are blind. They live in colonies and within each colony there are various castes or specialized groups adapted for particular duties. The largest number of individuals in a colony are the workers. These are either male or female, but are undeveloped or immature sexually and remain so throughout their life. Within each colony there will be found, also, a considerable number of individuals, each with an elongated head armed with a pair of long jaws shaped like cutlasses. These individuals are known as "soldiers" and are supposed to serve as protectors of the colony. Also within a colony will be found one pair or more of mature kings and queens and frequently various additional or supplementary queens.

Life in the colony is complicated, as with other highly specialized, social insects. The workers forage for food, which they find by traveling sometimes to a distance of many yards in underground galleries. They always work concealed. Timbers will be hollowed out inside, but a thin outer shell will always be left untouched. To outward appearances a beam that is completely destroyed inside may look to be quite sound. Sometimes colonies will cover a considerable area, amounting to many square yards. Usually it is very difficult to find out where the center or centers of the colony may be located. When compelled to cross a space into which they cannot burrow, as for instance a concrete wall, termites will build a gallery, or enclosed runway, within which they travel back and forth in darkness and security.

Outside of heated buildings the activities of termites cease during cold weather. Thus, a colony located in a stump or within rotted wood in the heart of an old apple tree may become totally inactive during cold weather. But within heated buildings activity may go on continuously.

Once a year, probably in June in the latitude of southern New Hampshire, there is a flight of specially developed winged termites. These individuals are brown in color, are not sensitive to light and have functioning eyes as well as wings. They emerge suddenly in large numbers from the colony and include both males and females. After flying a few yards or, at most, a few rods, they alight and such pairs as survive the flight settle down to found new colonies. The wings are promptly broken off near the body. This annual flight serves to spread the species, to avoid overcrowding and to found new colony groups.

STUDIES IN TERMITE CONTROL.

The data presented in this publication are concerned in general with the measures adopted to eradicate termites from an occupied public building in New Hampshire and to protect the building from further infestation, and in particular with the use of heat as a means of killing termites within timbers and floors.

The building in which the infestation was discovered is a modern hospital located in one of the cities of New Hampshire. The structure is divided into three principal parts: a central portion, a wing to right and another to left. The wings are connected to the central portion by corridors. The outer walls are built of stone and brick. Some inner walls, as indicated on the plans, are of brick. Most of the inner partitions, however, are wood studding, plastered.

The central portion of the structure is used in part for administration purposes. On the first floor are an office, waiting room, matron's room, doctors' room and a service wing. Above these are private rooms for patients. The basement of this part of the structure is fitted up for store rooms, laundry and boiler room.

Corridors forty feet long connect the administration building with the men's pavilion to the south and the women's pavilion to the north. These corridors have brick walls and at the place where each corridor enters the administration building, as well as the place where it enters the pavilion, there is a brick cross-wall with a fire door. The two pavilions are sub-divided into wards and private rooms, the partitions being of wood.

The hospital is located on a large plot of ground at the edge of the city in question. It has ample space of lawns all about it. There are some trees. South of the building there was situated, at the time that these studies began, a frame house and the remnants of a frame barn, both of them built many years ago.

The hospital is maintained in scrupulous order and every measure is adopted for hygienic cleanliness that may be found in any well-regulated institution of its purpose. Both the buildings and the equipment are modern and complete.

In the spring of 1917 a number of insects, which undoubtedly must have been winged termites, were observed by the hospital officers emerging from a crack under a door-sill in the opening leading from the corridor of the administration building into a room that was, at that time, used as a dispensary,

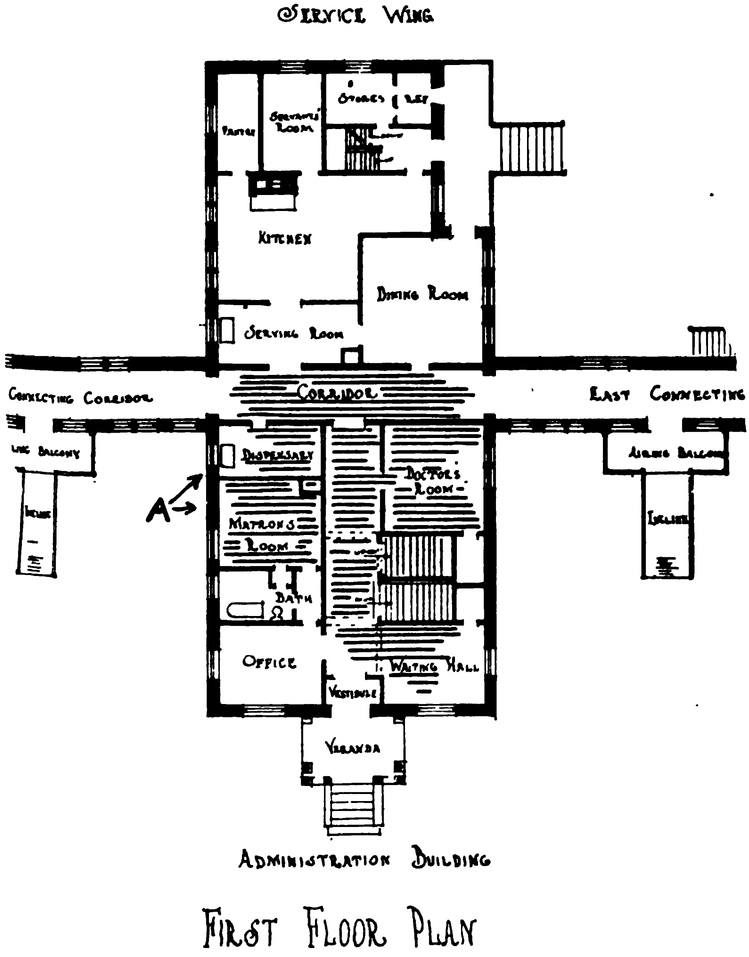


FIG. 1. Plan of the first floor of the administration building. The infestation on this floor extended through the area shaded in horizontal lines.

but has since been made a part of the matron's room. (Fig. 1, A). The emergence lasted for only a short time. While it caused anxiety to the hospital staff, nothing further was seen of the insects on that occasion and it was supposed that they were no longer present.

In the winter of 1918 their work was discovered in serious degree. At that time articles were being moved from one of the shelves in a store room in the basement of the administration building (Fig. 2, A.B.). As this task was in progress the partition to which the shelving was attached gave way. Some of the lath and plaster were removed, and it was found that the studding had been practically destroyed. The writers of this bulletin were then called into consultation and the work of eradication and control began.

The species of termite concerned proved to be the form commonly found in the central and northern states, *Leucotermes flavipes* Koller.

Workmen employed by the hospital began tearing out the basement partitions. As this job proceeded, more and more evidence of the extensive mining that had been accomplished by the termites was laid bare. Practically all of the partitions in the main part of the basement of the administration building had been attacked. (Fig. 2, A. B. C. D. E. F. G. H.). A brick partition separated this part of the basement from the boiler room. (Fig. 2, I.) But in the boiler room planks used to enclose a coal bin were found infested. The supports of two stairways, leading into the basement (Fig. 2, F. H.), had been attacked.

In the basement floor there are several hand holes, where turns occur in drain pipes and the like, located beneath the floor. These hand holes had wooden linings and in each case this wood was thoroughly infested.

The floor of the basement was cement. But the various wooden partitions had been built before the cement was poured. Therefore, the studding of the partitions was in direct contact with the sandy soil which underlies the basement. This may have furnished the means of entry by which the termites got into the basement, but of this no certain statement can be made. The basement floor is at a depth of four or more feet below the level of the ground outside. It may be that the termites burrowed beneath the basement wall and the cement floor and came up into the partitions, or it may be that they found access through some crack in the foundation walls where a partition was close by. In any event they had fairly riddled most of the partitions in this basement.

As the wood partitions were removed it was discovered that the insects had burrowed into some of the wood beams that support the floor timbers and the structure above. These wood beams rest on brick pillars. They are 10 x 12 inch timbers and for the most part are 18 feet in length. Two of these timbers had been so hollowed out by termites that they were structurally worthless.

In addition, it was discovered that the lower layer of the double flooring of the first or main floor of this building had been attacked. This lower layer is made up of soft wood boards. Above these is a hardwood flooring.

This led the search to the first or main floor where parts of the hardwood flooring were torn up in order to discover to what extent the boards under-

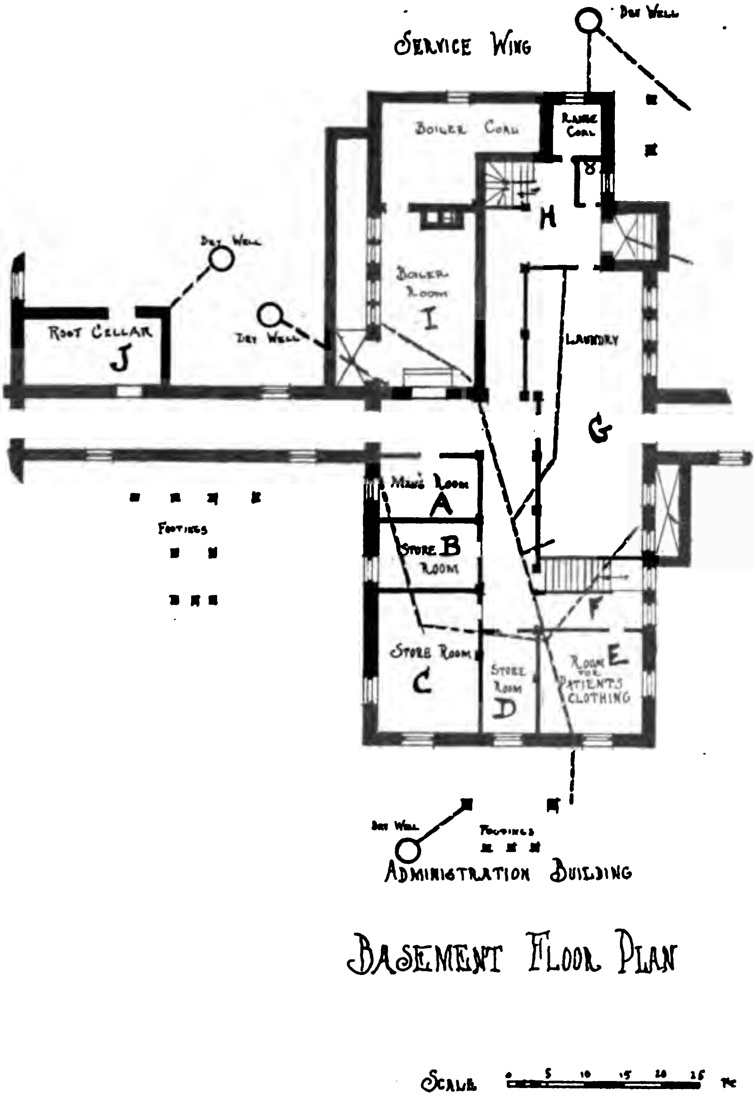


FIG. 2. Basement plan of administration building showing the partitions as they were at the time the infestation was discovered.

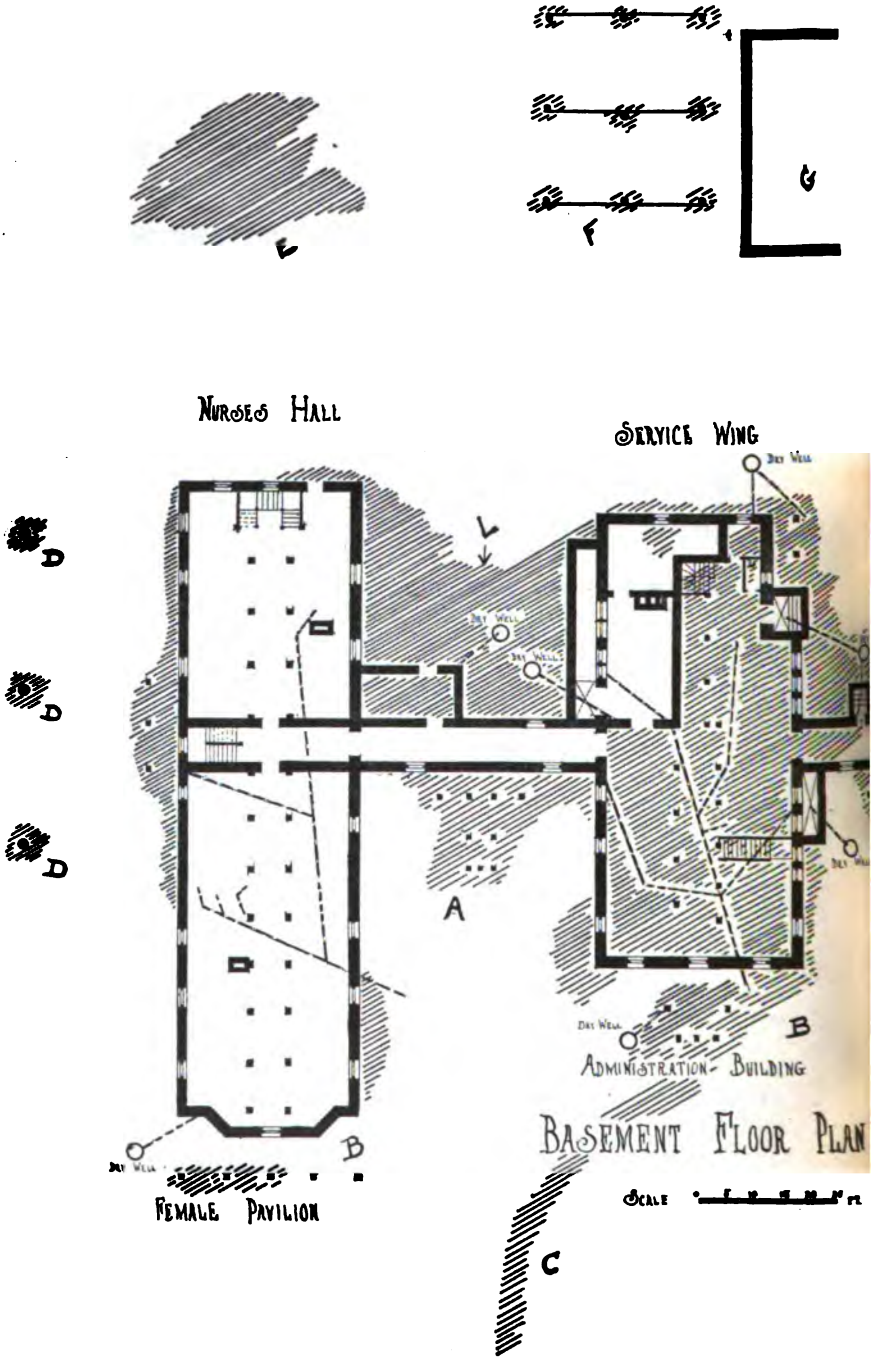
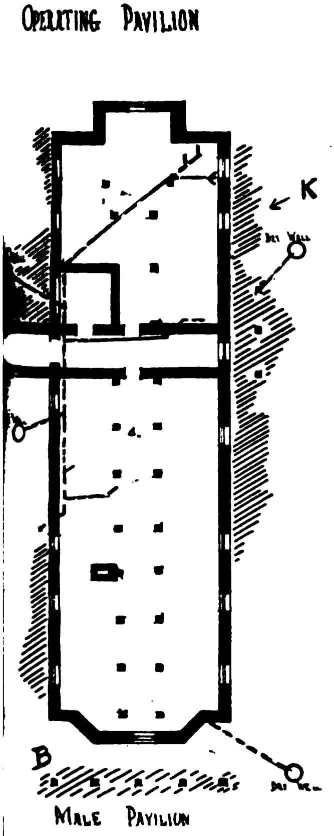
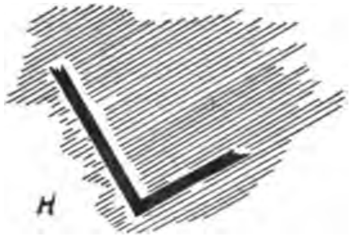
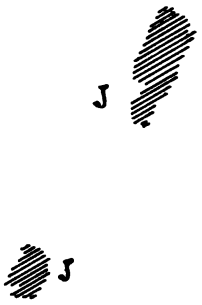


FIG. 3. General plan of the hospital buildings and surroundin







les were found through all of the area shaded in diagonal lines.

neath had become infested. Baseboards along the partitions of this floor were removed so as to ascertain whether the insects had extended their work into the partitions above. In order to determine this a section 6 inches long was sawed out of every other upright of these partitions, next to the floor. These sections gave uniform evidence that the work of the termites had ceased at about the floor level. Apparently, they had not yet had time to extend their ravages into the first floor partitions.

The task of eradication of the insects from the administration building now began.

All of the partitions and other material that had been taken out of the basement and first floor were burned. The spaces that were left in the concrete basement floor where the partitions had projected through to the ground beneath, were filled with cement so that the entire basement presented a continuous floor of concrete extending to the outer walls. The linings of hand holes were removed and burned.

Stairways were taken apart, or the lath and plaster removed far enough to disclose the upper limits to which the termites had mined. They were reconstructed so as to rest on the concrete floor. The infested boards in the boiler room were removed and burned.

It was necessary to remove two of the main supporting beams. In order to do this the central part of the building was supported with temporary timbers; the large beams—or what was left of them—were taken down from the brick pillars; and new beams were got into position by placing planks side by side vertically and bolting these together.

There was no way of making really certain that all material carrying termites had been removed. On the contrary, it was more than likely that some of the flooring and other wooden parts still held large numbers of the insect. It will be noted that the laundry for the hospital was located in this basement. Both as to heat and moisture this furnished conditions well suited to the further increase of the pest, if living specimens remained within the building.

In this emergency it was decided to attempt extermination of any termites remaining in the basement by means of heat.

Experiments were first carried out to determine the time and temperature factors that would be required for killing the pests within timbers. It was necessary not only to know what temperature would be required and for how long a period where the termites were more or less directly exposed to the heat, but also to determine what factor should be taken into account in order to make certain that killing would take place within heavy supporting beams, since there was serious probability that beams that had not been removed contained numbers of the termites.

Blocks of spruce wood 10 x 10 x 10 were prepared. Each block was sawed in half and bolts arranged so that the two halves could be rejoined securely. The surface of the two halves, where they were joined, was planed. A square of asbestos measuring 10 in. each way and 1-4 in. thick was fitted between the two halves. At the center of the asbestos a hole was cut, measuring 1 in. square. When the two halves were joined, with the asbestos board between this provided a small cell 1 in. square and 1-4 in. deep in the center of the block.

In the experiments, ten termites were placed in the cell in each test. The halves were then bolted together and the block was placed in a Freas electric oven provided with thermostat control. The block was allowed to remain in the oven for 24 hours at various temperatures, ranging from 155° F. down to 95° F. The tests were started at a temperature of 155° F. and in successive tests this was dropped until a point was reached at which the termites were not killed. It was found that a temperature of 120° F. continued for 24 hours, resulted in the death of all of the termites in three tests, but a temperature of 95° F., continued for 28 hours failed to kill them. The detailed results are given in the following table:

TEMPERATURE TESTS

Killing Effects of Heat on Termites Placed in Center of Spruce Block 10x10x10

No. of Insects	*Temperature*	*Time*	*Results*
10	155°F	24 hrs.	All dead
10	155°	24	" "
10	145°	24	" "
10	145°	22	" "
10	135°	24	" "
10	130°	24	" "
10	130°	24	" "
10	125°	24	" "
10	120°	24	" "
10	120°	24	" "
10	120°	24	" "
10	95°	28	2 dead, 8 alive

Following these preliminary tests, arrangements were made for installing supplementary steam pipes in the basement, of sufficient capacity to raise the temperature within the entire basement to 130° F. or more and to maintain it there.

In the rear of the basement was a small boiler capable of carrying a steam pressure of 50 lbs. or more, (Fig. 4, A.). A system of pipes was installed connecting with this boiler. Two inch pipes were used, arranged in three horizontal sections of seven pipes each. The pipes were supported on temporary brackets about 18 in. below the basement ceiling. They were arranged with only sufficient slope to drain off condensation. Each section extended the length of that part of the basement in which it was placed. The general arrangement of the system is shown in Fig. 4. The total amount of radiation surface was 700 feet, or about one foot to each 20 cubic feet of space in the basement.

A preliminary test was made and the system was found to be in good working order. The following day, at 6.00 p. m., steam was let into the pipes at a pressure of 40 lbs. Before the steam was turned on, all cracks in windows and doors were sealed with paper. The temperature in the basement just before steam was admitted was 80°. The date was March 22 and the temperature outdoors was that of moderate spring weather.

A thermograph was placed in the basement about two-thirds of the distance from the boiler room to the front wall and about 6 feet above the basement floor. It was located midway between two of the banks of steam pipes but not immediately adjacent to them. Close beside the thermograph was set a block of spruce wood 8 x 8 x 8 containing eight living termites in a small cell in the center. The thermograph and the spruce block with its termites were left in this position for the next 24 hours.

At five points in the floor above a half-inch hole was bored and a thermometer, run through a cork, was lowered through each hole. Readings were recorded from these thermometers every hour during the following 24 hours.

The remainder of the building continued in use throughout the treatment. The administration offices served their usual purpose. Patients remained in their rooms above without knowledge of the treatment going on in the basement.

Within an hour after the heat was turned on the temperature began to rise, and this rise soon became rapid. By 9.30, or 3 1-2 hours after steam was admitted, the temperature in the upper part of the basement area had reached 120° F. Two hours later it had risen 15° further to 135° F. About six o'clock the following morning it was necessary to shut off steam, in order to make a slight repair to the boiler. The temperature in the basement promptly dropped to about 120° F. in the next 45 minutes, but when steam was turned on it rose fairly rapidly again and by ten o'clock had regained the high point of the earlier hours. At 4.00 p. m. the temperature began to rise still further and when heat was finally turned off at 6.00 p. m., 24 hours after the treatment started, the temperature had reached 140° F.

The readings of the five thermometers were averaged and have been reduced to a curve indicated by the dash line A in Fig. 5. The readings of the thermograph are indicated in the dotted line B of Fig. 5. It will be noted that the curve A runs higher than B, but it will be recalled that the thermometers from which the record A is taken were nearer to the basement ceiling than was the thermograph.

When the treatment was concluded, the spruce block containing 8 termites was opened and all were found to be dead. In addition, they were somewhat brown and brittle, as if they had literally been baked.

After the heat treatment had been finished, the task of replacing and repairing damaged woodwork on the main floor was carried out. Much of the flooring had been taken up in searching for the termites and, as already related, much of the studding had been cut off at the lower part. This work was now carried further and flooring was replaced or renewed over a considerable part of several rooms. In doing this the workmen took up and removed many boards containing termite galleries and in a number of these there were termites present. But all termites found were dead. No living termite was found within this building in any subsequent work.

In the basement new partitions were erected, built of tiling. As already explained, the entire basement floor had been fully cemented. The walls of the basement were carefully examined for possible cracks and throughout the entire season a close watch was kept for any possible entry of termites through the walls. In no case were they discovered. The areas on the first floor where flooring was removed and replaced are indicated by the shaded portion shown in Fig. 1.

Meanwhile, and for a long time afterward, work was in progress outside the hospital building to discover termites and to try to get rid of them. The surroundings of the building are shown in Fig. 3. The shaded parts indicate areas in which termites were found. It will be noted that there was a very general, widespread and serious infestation.

To right and left of the administration building there is an incline leading up to the corridors that connect the pavilions with the administration building. (Fig. 3, A. A.). That part of these entrances which was near the ground was found to be infested. The lower part, therefore, was removed as far as the infestation had proceeded. A concrete foundation for the incline was built in each case.

On the front of the administration building and on the front of both pavilions there are porches (Fig. 3, B. B.). Beneath the floor of these porches was lattice work, extending in some places to the ground. A considerable part of this was infested. The lower part of the lattice was sawed off so that there would be a clearance of 6 inches between the ground and any lattice.

At the rear of the administration building, also, there is a porch and at the rear of the corridor leading to the men's pavilion there is an outside wooden stairway. Many termites were found in the neighborhood of this rear porch and the stairway was badly tunneled. Termites had gained access to the stairway through cracks in brick piers on which the posts supporting the stairway were placed. Posts and infested parts of the stairway were removed and the structure rendered termite-proof.

In the front of the administration building a narrow board walk followed the entrance driveway in a curving line to the street. On lifting this board walk many termites were found beneath. The entire board walk was removed and destroyed. (Fig. 3, C.)

Just north of the women's pavilion were three old apple trees (Fig. 3, D, D, D). These appeared to be vigorous but had some hollows and some dead wood within the trunks and larger limbs. They were discovered to be thoroughly infested. All three trees were removed. The earth was dug away from around the roots and these were pulled out and destroyed, along with the rest of the trees.

At the rear of the women's pavilion and located 60 feet from it was a low mound of earth containing various bits of board. Termites were discovered here and this material was burned. (Fig. 3, E.)

At the rear of the administration building and about 70 feet away were sets of posts supporting clothes-lines. Termites were discovered here, also. These posts were removed and in their place new posts were set which had been treated with creosote and which were now imbedded in cement piers (Fig. 3, F.)

Immediately adjacent to these posts is a structure open on one side, used for temporary storage of doctors' automobiles. While this structure is of wood, it rests on a cement foundation. No termites were discovered in any part of it (Fig. 3, G.).

South of the men's pavilion and distant about 75 feet were the remains of an old frame barn, including the cellar, old foundation stones and some large timbers lying on the ground. (Fig. 3, H.) Large numbers of termites were discovered here. Some of the old timbers were infested and these were destroyed. Repeated search disclosed numerous termites on turning over stones. These were destroyed by the use of hot water and later by the use of a mixture of Phinotas oil and water, as will be described later. Southwest of this barn and still farther away from the hospital buildings was a frame house (not shown in Fig. 3). There was some evidence of termite work in the lower part of the house. Later, this building was moved away from the premises.

Between the frame dwelling and the hospital building were the stumps of two or three trees that had been cut off close to the ground and graded over. These were uncovered and were found infested. They were dug out as much as possible and were treated in the same fashion as the earth beneath the stones of the barn. Also, some buried pieces of boards were found in this general area where they had been covered by grading. These were treated in similar manner, (Fig. 3, J. J.)

Toward the rear of the men's pavilion a small hotbed about 4 feet square had been built, immediately in front of one of the basement windows. (Fig. 3,K). This was found to be riddled. Large numbers of termites were discovered in the dry manure remaining within the hotbed. All of this was removed and destroyed.

In the rear of the basement corridor leading from the administration building to the women's pavilion a root cellar had been constructed two or three years before. The walls were of cement and brick and the floor of cement. There were no outer windows. (Fig. 3, L; Fig. 2, J.) The insects had gained entrance through cracks in the cement floor. From the point of entrance they had constructed covered galleries over the floor and wall to a distance of several feet. The root cellar received a two-fold treatment. First, it was fumigated with carbon bisulphide, which was poured into the cracks in the cement, the building being kept tightly closed for a day or two. Following this the cracks were sealed by filling them with hot tar. This was used in order to have a somewhat flexible material that presumably would not open up, allowing further entrance of the pest. Since this was done, no termites have been discovered in the root cellar, although for a long period thereafter there were large numbers of them constantly disclosed under trap boards placed in the adjacent area outside.

Because of the large numbers of termites that were discovered through much of the surroundings of the building it was felt that a good deal of danger existed that the pest might again find entrance. With the intent of reducing this danger or perhaps obviating it, the earth next to the foundation wall and to a depth of about 3 feet was removed all around the outer walls of the entire structure. This made a trench about 12 in. to 18 in. wide. The

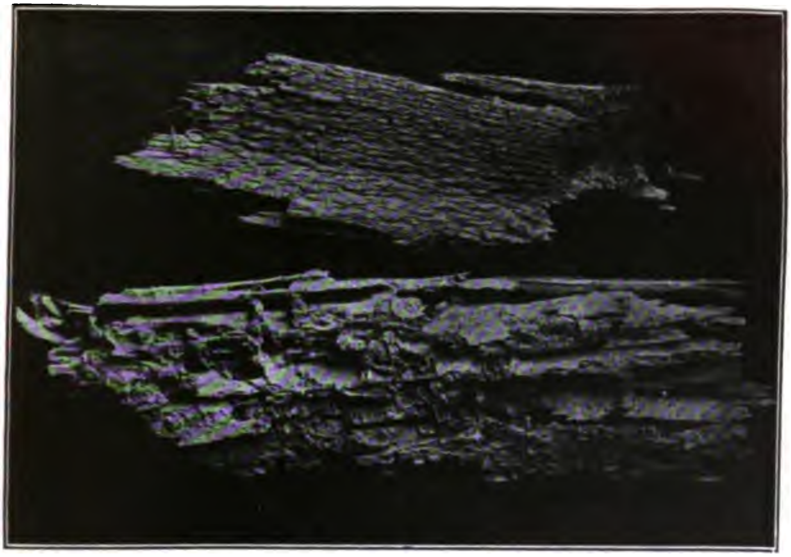


PLATE 1, A. At the top is a small section of a beam, showing surface apparently sound and giving no indication of the damage beneath. The lower piece shows galleries filled with frass.

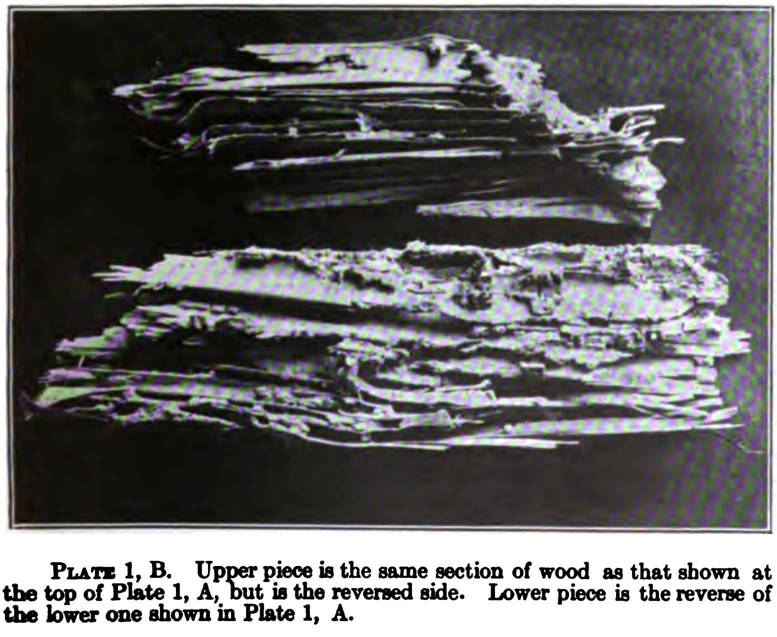


PLATE 1, B. Upper piece is the same section of wood as that shown at the top of Plate 1, A, but is the reversed side. Lower piece is the reverse of the lower one shown in Plate 1, A.

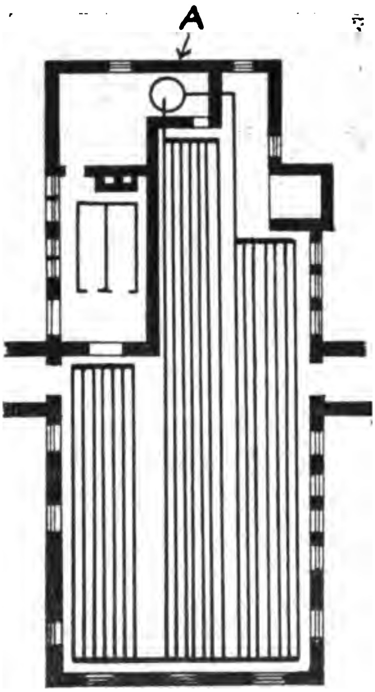


FIG. 4. Diagrammatic plan of supplementary heating coils installed in basement of administration building.

earth, as it was removed, was treated with Phinotas oil and water and carted away to a dump.

In this work, and in the treatment of termites found under stones at the old barn cellar and in similar places, Phinotas oil was used because it mixes promptly with water and has strong insecticidal properties. It is easily prepared for use simply by pouring the oil into water. Water was used in such amount as to give a dilution of one-half of one percent. It was found that this dilution readily killed termites. So far as experience in this place is concerned, the ground so treated remains unsuitable to termites for a considerable or perhaps an indefinite period thereafter.

The trench next to the foundation walls was filled with cinders. The intent of this was to provide next to the walls a band of material which presumably the termites would find less suitable than earth containing organic matter. It was expected, also, that the cinders would remain rather dry throughout the season when the termites were most active and, therefore, would offer a medium not well adapted to their galleries. The bottom of the trench was treated with Phinotas oil and water before the cinders were placed in it. Up to the present time no further evidence of termites has been discovered in the trench or in or on the foundation walls, although throughout the two seasons that have followed many termites have been found short distances away.

It was thought that the work of fighting the pests in the grounds outside the building would be facilitated if it were possible to discover the source or sources from which they were working toward the building. In order to attempt this, small blocks of pine wood, four of five inches square, were placed on the ground, every three or four feet all the way around the entire circumference of the building, two or three feet away from it. These blocks were turned over and examined every two or three days. The result of this was the disclosure that by far the greater part of the entire area surrounding the building appeared to be supporting termites. They were especially numerous in the rear of the building on the north side of the women's pavilion and on the south side of the men's pavilion, but they were found scatteringly in other places. It was not possible to determine from what direction or directions they were spreading toward the building. In fact, the condition seemed rather to be that the ground was pretty well infested in almost every direction.

The probability is that there were, and are, pieces of board and other bits of wood scattered through the ground here and there over much of the area, since a good deal of it represents a fill made by the contractors in grading, after the hospital was built. Odd pieces of board and other bits of wood were buried in the process of grading.

Very large numbers of termites were disclosed by the traps in the area back of the root cellar (Fig. 3, L.). A large, flat board was placed on the ground here. This was turned over every day and the termites found were killed with boiling water. Thousands were destroyed. By using boiling water instead of Phinotas oil at this place the ground was not rendered unsuitable for the termites and they continued to come to the board trap.

It was felt that there was danger that the termites would construct galleries over the concrete and stone posts to the lattice work or flooring of the porches. Also, at the inclines (Fig. 3, A. A.), where concrete had been substituted for the wooden parts next to the ground, it was feared that galleries might be constructed to reach the wood. In order to forestall this, a band of tree tanglefoot was applied around the brick posts of the porches beneath the lattice work and a similar band around the concrete supports for the entrance In other places where it was feared that galleries might be constructed, tanglefoot was used in the same fashion. In no case were termite galleries discovered. The bands were kept fresh by combing out at frequent intervals.

Three seasons have now elapsed since the control work was begun. The closest possible watch has been kept for termites within the administration

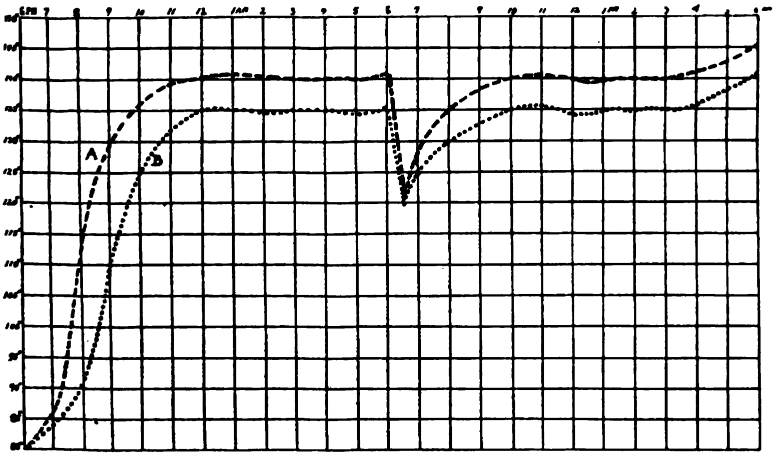


FIG. 5. Graph of temperature records. The dash line A is the average of thermometers lowered through floor. The dotted line B is the thermograph record.

building and other parts of the hospital throughout that period, but none have been discovered within. The numbers recovered outside of the building have diminished.

During the last year, work has been in progress on still another wing south of the men's pavilion and connected to it by corridors. This new wing is located where the frame house and barn stood. Thorough precautions were taken to avoid permitting termites to get a start in the new wing. It will be noted that this wing is built in part where large numbers were found in the barn cellars.

The basement of the new wing was constructed with special care to render it proof against entrance by termites. While the building was being constructed, an attempt was made to keep boards, beams and other structural material elevated on skids and protected by tanglefoot or by Phinotas oil. The new building is now practically completed and no termite has been discovered within it.

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The Toxicity of Various Fractions and Combinations of Fractions of Coal-Tar Creosote to Wood-Destroying Fungi [1,2]

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Considerable work has been done in the past to determine the toxicity to wood-destroying fungi of various fractions of coal-tar creosote and many other wood preservatives. However, much of this work is of little or no practical importance for either of two reasons: First, wood impregnated with the creosote was not used as the substrate, and, second, the minimum percentages of single fractions are of little or no concern, but rather a combination of certain fractions with the elimination of certain others. That is, the most probable result which obtains after a creosoted timber is exposed to natural weather conditions is the evaporation and leaching of the lighter and more soluble parts of the mixture.

Among the later workers in this field are Humphrey and Fleming,[3] who determined the toxic point of some fractions of creosote, but who used single fractions in all cases and combined them with nutrient agar, conditions in no way comparable with those in actual practice. The literature regarding this line of investigation has been sufficiently reviewed in the paper just cited so that no review will be made here. The discrepancies between the so-called petri-dish method used by the above-mentioned writers and the conditions met with in treated timbers are obvious. In the first place, the emulsion which is formed when creosote and agar are thoroughly mixed is by no means permanent, and, even in *very rapid* cooling of the agar after the emulsion has been formed, it is quite probable that the individual minute droplets have coalesced to form droplets of considerable size resulting in a more or less irregular mixture varying from globules of the insoluble portions of the creosote to nutrient

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[1] Received March 21, 1921.

[2] This work was begun in the Research Laboratories of the Missouri Botanical Garden and completed in the Laboratory of Forest Products, School of Forestry, University of Idaho. Thanks are due to the Missouri Botanical Garden for the privileges of the laboratories, and to Doctor Hermann von Schrenk for suggestions.

[3] "The Toxicity to Fungi of Various Oils and Salts, Particularly Those Used in Wood Preservation," U. S. Department of Agriculture, *Bulletin* 227 (1915), 1, Plates 1-3.

agar containing varying proportions of the water-soluble portions of the creosote mixture. In the second place, it is a well-known fact[1] that the toxicity of a certain substance may be altered materially by the presence of other substances. This may be particularly true where there are such complex relations as would exist between emulsions, colloids, electrolytes, and non-electrolytes, such as are found in an emulsion of coal-tar creosote in nutrient agar. On the other hand, the use of impregnated wood as a culture medium for fungi causing wood decay offers no particular difficulty, and there is more valid reason than not why wood should be used in preference to synthetic media. It has seemed to the writers that sawdust, although not physically the same as solid wood, is the most appropriate medium for the culture of wood-destroying fungi in such studies as are presented here.

METHODS

In the present study, creosote (von Schrenk and Kammerer No. 3072) derived from coal tar was used. This oil, when analyzed[2] according to the method[3] now standard in the American Railway Engineering Association, the American Wood Preservers' Association, and the American Society for Testing Materials, gave the following results:

Sample No.	3072
Sp. gr. at 38° C.	1.048
Water	0.0
DISTILLATION TEMPERATURE °C.	Per cent
210	3.6
235	32.4
270	23.8
315	16.9
355	15.4
Residue	7.9
TAR ACIDS	
Per cent by volume	7.5
Sp. gr. fraction, 235°–315°	1.038
Sp. gr. fraction, 315°–355°	1.100

FRACTIONATION—For the experimental work here recorded, the creosote was fractionated as follows:

1—Undistilled.
2—Fraction below 210° C.
3—Fraction between 210° and 235° C.
4—Fraction between 235° and 270° C.
5—Fraction between 270° and 315° C.
6—Fraction between 315° and 355° C.
7—Residue above 355° C.
8—Combination of all fractions, except below 210° C.
9—Combination of all fractions, except between 210° and 235° C.
10—Combination of all fractions, except between 235° and 270° C.
11—Combination of all fractions, except between 270° and 315° C.
12—Combination of all fractions, except between 315° and 355° C
13—Combination of all fractions, except residue above 355° C.

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[1] A Le Renard, "Influence du Milieu sur la resistance du *Penicille crustace* aux substances toxiques," *Ann. sci. nat bot.*, [9] 16 (1912), 277.

[2] Thanks are due to Dr. A. L. Kammerer, Consulting Timber Engineer, St. Louis, for making this analysis and for fractionating the creosote and combining the various fractions.

[3] *Proc. Am. Wood Preservers' Assoc.*, 1917, 309.

PREPARATION OF MEDIA—All fractions and combinations of fractions were entirely soluble in 95 per cent ethyl alcohol, except the residue above 355° C. The following method was therefore employed: Twice the maximum concentration (calculated in weight of creosote to weight of air-dried wood) of creosote was dissolved in 100 cc. of redistilled 95 per cent ethyl alcohol. One-half of this alcoholic solution was added slowly and with constant stirring to 20 g. of air-dried yellow poplar (*Liriodendron tulipifera*) sawdust in a large beaker. This amount of alcohol was just sufficient to saturate the sawdust so that no free liquid remained, and an evenly impregnated sawdust was obtained.

The remaining 50 cc. of alcoholic solution were diluted to 100 cc. with alcohol, giving a concentration of creosote equal to one-half the former. This procedure was carried on throughout the range of concentrations used. The impregnated sawdust was spread out on clean glass plates for 24 hrs., in which time all of the alcohol had evaporated. The sawdust now weighed exactly 20 g. plus the weight of the creosote calculated for each dilution. Hence, no creosote was lost during the 24-hr. exposure to the air. Even had there been a little loss in weight, this would have been of no practical importance, since substances so volatile that they would be lost in so short a time would be of little or no practical importance in timber preservation.

The same procedure was followed in the experiments where western white pine (*Pinus monticola*) sawdust was substituted for the yellow poplar sawdust.

To prepare intermediate concentrations of creosote in sawdust, equal amounts of others were mixed. For example, a 3 per cent concentration was prepared from equal amounts of the 2 and 4 per cent material. In some cases, however, it was also necessary to make a new series of dilutions.

As has been said, one fraction (the residue above 355° C.) was not entirely soluble in alcohol. In this case, the same procedure was employed and the remaining insoluble substances were added proportionately by weight to the various flasks.

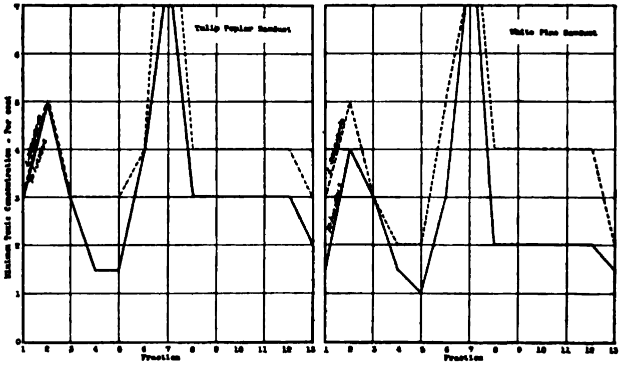
After the alcohol had evaporated, 3 g. of the impregnated sawdust were placed in each of four 8-oz. bottles. Twenty cc. of distilled water were then added to each bottle containing the white pine, while 12 cc. of water were added to each of the flasks containing the tulip poplar sawdust. In each case this amount of water was just sufficient to saturate the sawdust thoroughly without any free water remaining.

STERILIZATION—The media were sterilized as follows: The bottles were tightly corked with suberin stoppers surrounded by heavy paraffined paper and placed in a rigid wooden frame into which the corked bottles would fit tightly, so that there would be no possible chance of the corks blowing out or becoming loose while being autoclaved. All of the bottles were autoclaved for 20 min. at 20 lbs.

pressure. Immediately after autoclaving, the corks were removed and previously sterilized cotton plugs were substituted under sterile conditions to avoid all possible chances of contamination. The bottles were then ready for inoculation.

A check was run on this method of sterilization in order to determine whether any creosote was lost during the process of autoclaving. A series of culture bottles (not including the corks), prepared as above described and carefully weighed to the fourth decimal place before and after autoclaving, showed no loss in weight.

PREPARATION OF CULTURES—The fungi used were *Polyporus lucidus* (Leys.) Fr. and *Lenzites saepiaria* Fr. Duplicates were prepared for each concentration of creosote. Three control sets were also prepared for each wood, one with natural sawdust, a second with sawdust treated with alcohol at the rate of 50 cc. per 20 g. of sawdust, and a third with sawdust treated with alcohol at the rate of 100 cc. per 20 g. of sawdust. In each case the alcohol was evaporated as previously described by spreading the sawdust on a glass plate and exposing the latter to the air for 24 hrs.



TOXICITY OF THE VARIOUS FRACTIONS AND COMBINATIONS OF FRACTIONS OF COAL-TAR CREOSOTE TO *Lenzites saepiaria* AND *Polyporus Lucidus*

The culture bottles were inoculated by means of small squares of agar from plate cultures of the respective fungi. After inoculation, the bottles were incubated at 28° C. until the sawdust in the control flasks was entirely permeated with the fungous mycelium. This required about 18 days in the case of *Polyporus lucidus* and about 25 days in the case of *Lenzites saepiaria*. Growth was also slower on the white pine sawdust than on the tulip poplar sawdust. The cultures were carefully examined with a hand lens to determine whether, and if so to what extent, the mycelium had permeated the sawdust. In the foregoing curves the minimum toxic concentration expressed in per cent dry weight of the sawdust is shown on the abscissas.

DISCUSSION OF RESULTS

The data are self-explanatory. The results indicate no toxic effects of any single distilled fraction or combination of fractions of the coal-tar creosote below a concentration of 1 per cent, calculated on the weight of air-dried sawdust. That is, there was no visible cessation of growth of either *Lenzites saepiaria* or *Polyporus lucidus* below a 1 per cent concentration. In a majority of cases, the toxic point, which we have defined as the minimum percentage of the creosote which will completely inhibit the growth of the organisms, lies between 2 and 4 per cent. Because of the discrepancies between the two methods, as pointed out elsewhere in this paper, the results of our experiments are at variance with those obtained by Humphrey and Fleming.[1] This was to be expected, and a comparison of the results could not be beneficial here because of the many factors which would naturally lead to differences in results. The comparison of the results of the two methods can only be left to their merits in practical application, and either one may be discarded if a preferable method is suggested for the testing of the toxicity of wood preservatives.

From the data obtained, it is evident that *Lenzites saepiaria* is more resistant to greater concentrations of coal-tar creosote than is *Polyporus lucidus*. As would be expected, the percentage of creosote necessary to inhibit the growth of wood-destroying fungi varies with the wood. The two most toxic fractions are those which distil over between 235° and 270° C. and between 270° and 315° C. There is no great difference in the toxicity of any of the combinations of the various fractions except when the residue above 355° C. is omitted. Since this residue is toxic only in very high concentrations, its absence from the combination of the others would tend to increase their united toxicity.

It may be argued that the computed percentages of creosote, calculated on the basis of dry weight of the sawdust, are not the actual values which should be taken into consideration because of the amount of water present during the growth of the organisms. However, we feel that there would be little in favor of such an argument when compared with actual practice. In commercial practice the amount of impregnation is calculated as pounds of creosote per cubic foot of wood, seasoned either before or during the process of impregnation. Thus, the percentage of creosote ultimately becomes a question of weight, depending upon the specific gravity of the wood. Moreover, in actual practice, impregnated timbers, such as railroad ties, may be placed under moisture conditions very favorable to the support of fungous growth. Under these conditions, moisture would be absorbed by the wood. The present experiments were attempts to imitate these natural conditions which are conducive to timber decay.

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[1] *Loc. cit.*

UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1037

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief.

Washington, D. C. PROFESSIONAL PAPER August 19, 1922

THE CONTROL OF SAP-STAIN, MOLD, AND INCIPIENT DECAY IN GREEN WOOD, WITH SPECIAL REFERENCE TO VEHICLE STOCK.[1]

By NATHANIEL O. HOWARD, *Pathologist, Office of Investigations in Forest Pathology.*

(In cooperation with the Forest Products Laboratory of the United States Forest Service, Madison, Wis.)

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INTRODUCTION.

During periods of transit and storage, previous to its ultimate manufacture, green timber containing a high percentage of sapwood often suffers considerable damage. This is particularly true during the late spring and summer months when deterioration brought about mainly through a discoloration of the sapwood, known as sap-stain, sometimes necessitates degrading on a large scale. This staining of timber has occasioned severe losses in Europe as well as in the United States, and many expensive investigations have been made to determine the nature of the stain and to discover a satisfactory remedy.

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[1] The writer wishes to acknowledge his indebtedness to Mr. C. J. Humphrey, in charge of the Laboratory of Forest Pathology, Bureau of Plant Industry, in cooperation with the Forest Products Laboratory, Madison, Wis., for facilities and for advice in outlining the work; to Dr. Charles Thom and Miss Margaret B. Church, of the Bureau of Chemistry, for the identification of mold fungi; to Mr. H. D. Tiemann, physicist and specialist in kiln drying, Forest Products Laboratory, Madison, Wis., for the loan of photographs; to Mr. Joseph Ashcroft, of Poplar Bluff, Mo., for cooperation in the experimental dipping of spokes; and to all others who, by information, suggestion, or criticism, have contributed to the preparation of the manuscript of this bulletin.

The molding of green timber has frequently been confused with sap-stain as well as with incipient decay. However, in so far as the production of permanent stain or the effect upon the durability of the wood is concerned, molding is of comparatively little importance. Incipient decay caused by true wood-destroying fungi, on the other hand, is of great importance.

Early in the year 1918 the attention of the Office of Investigations in Forest Pathology was called to staining and molding occurring in green raw material by the wood-stock committee representing the National Implement and Vehicle Association and other vehicle and vehicle parts manufacturers through the Forest Products Laboratory of the United States Forest Service, Madison, Wis. The present investigation arose in connection with raw hardwood stock used in the manufacture of escort wagons and artillery carriages. A large quantity of this material was at that time being sawed or turned, largely from green instead of seasoned stock and shipped green from the saw. In some cases it was found necessary to cull severely such stock at destination, owing to the presence of mold, stain, or incipient decay which had developed during transit and while in storage. In cooperation with the Forest Products Laboratory and the wood-stock committee, a questionnaire[2] was sent to a number of the contractors for Army vehicles and parts and to producers of wood stock. Personal investigations were also made of the conditions existing at 45 mills and factories engaged in the sawing of timber, dimension stock, and veneer, or in the manufacture of airplanes, furniture, flooring, handles, vehicles, and vehicle parts. Most of these mills were located in the central and southern portions of the United States and were directly concerned in the production of war material. The object of both questionnaire and personal investigations was to gain information concerning the general sanitary conditions existing in the woods, railway cars, sheds, warehouses, and kilns; the details of manufacture of many vehicle parts; the extent of deterioration occurring in green raw material; the financial losses occasioned thereby; and, particularly, any practical methods of handling green wood stock that would prevent the development of stain and mold therein.

The investigations showed that many of the firms had experienced considerable pecuniary losses, which were due to the necessity of using a high percentage of green stock; to a shortage of cars, resulting in the congestion of material in the woods and railroad yards; to lack of time for the proper air seasoning or kiln drying preparatory to shipment; and, finally, in some cases to a failure to understand the conditions necessary to safeguard the stock while in storage or in transit. Many of these losses due to emergency will be considerably reduced upon return to normal conditions.

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[2] National Implement and Vehicle Association and other Vehicle and Vehicle Parts Manufacturers. Information Division of the Wagon and Vehicle Committee and the Wheel Manufacturers' War Service Committee. Wood Stock Committee. Sap-stain and mold in green lumber. Nat. Implement and Vehicle Assoc., etc., Bul. 24, 2 p., 1 fig. 1918. A. B. Thielens, chairman. Multigraphed.

Some manufacturers consider it important that, in order to overcome losses due to checking, certain kinds of stock produced at many of the smaller mills be shipped to them in a green rather than in a partly seasoned condition. They claim that these mills, not being equipped for the proper drying of stock preliminary to shipment, make it necessary for the manufacturer to insist that material from such sources be shipped in a green condition to the factory, where suitable means for storage and drying are maintained. Close attention must be paid to the handling of this material in transit or in storage if deterioration due to fungi is to be prevented.

The necessity for a careful conservation of timber in the United State is becoming more and more apparent (*53*,[3] *54*[4]). Measures, then, that will assist in preventing or reducing losses due to fungous attacks are of importance.

This bulletin presents a brief review of our knowledge of sap-stain and mold, a consideration of the causal organisms responsible for such deterioration in green wood stock, the results of the new investigations, and finally a summary of some of the important methods of control.

SAP-STAIN.

The "bluing," or sap-stain, of pine timber has been observed in Europe for many years. Both Hartig (*17*, *18*) and Frank (*11*) refer to it in their investigations of plant diseases. Rudeloff (*36*) studied the effect of blue stain on the strength of pine wood. Münch (*31*) not only examined the properties of blued coniferous wood but also investigated the causal organisms and determined the optimum conditions for their development in the wood. In the United States considerable attention has been given to the subject by such investigators as Von Schrenk (*41*, *42*, *43*), Hedgcock (*19*, *20*), Rumbold *37*, *38*), Weiss and Barnum (*56*, *57*), and Bailey (*5*). Many of the investigations have been made in connection with the sap-stain of hardwoods as well as conifers.

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[3] The serial numbers (*italic*) in parentheses refer to "Literature cited" at the end of this bulletin.

[4] These two reports on Senate Resolution No. 311 by the Forest Service of the United States Department of Agriculture may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 25 cents and 5 cents, respectively, per copy.

DEFINITION OF SAP-STAIN.

The term "sap-stain" refers to the blue, green, brown, or red discoloration which often may be observed in the sapwood of timber derived from several kinds of broad-leaved and coniferous trees. It must not be confused, however, with the superficial discolorations produced mechanically, i. e., by collections of dirt and coal dust, by deposits from the drip in leaky cars and sheds, or from the condensed moisture in kilns. Such deposits may occur upon heartwood as well as sapwood. Neither should it be confused with the common blue-purple stain apparent when rusty saws are used on certain green wood, such as oak. This stain results from the reaction between the tannic acids of the wood and the iron compounds from the saw. Finally, it must not be confounded with the variously colored superficial growths of molds or the more or less deep seated sap-rot, with its brown to bleached appearance and its tendency to produce a punky consistency of the sapwood itself.

There are two quite generally recognized classes of sap-stain: (1) The chemical stain, said to be produced by chemical reactions brought about through the agency of certain oxidizing enzyms present in the wood itself; and (2) fungous stains known to be caused by several species of fungi.

CHEMICAL STAINS.

Chemical stains due to enzyms cause discolorations in both the sapwood and the heartwood of sugar pine and hard maple (Tiemann, *51*, p. 185; also Pratt, *34*, p. 305–307). Such stains develop during air drying, particularly under warm and humid conditions, or in the kiln, and give more or less permanent discolorations to the wood, to wit, a brown stain in sugar pine (fig. 1) and a cherry color in hard maple. These defects cause degrading (*34*) and often result in financial losses. According to Bailey (*5*), when freshly cut sapwood of alder, birch, cherry, or red gum is exposed to the air during extremely warm and humid weather, chemical reactions often take place and within a few hours produce colored substances in the wood. Bailey (*5*) states that the microscopic examination of sections of such wood indicates that the colored substance develops particularly within the pith rays and the parenchyma cells. He states that certain soluble enzyms which assist in the oxidation of organic compounds and are of prime importance in the nutrition and growth of living organisms are widely distributed in plants and animals and may also produce post-mortem discolorations of certain organic compounds (see also Clark *8*, *9*). Yoshida (*59*) discovered in 1883 that an oxidizing ferment is responsible for the oxidation of the latex in certain species of Rhus and the formation thereby of black varnish, or lacquer. Investigations have also shown that discolorations in fruit juices, vegetables, cereals, mushrooms, and various soft plant tissues are brought about through the agency of certain oxidizing ferments, the oxidases and the peroxidases (Asō *1*, *2*, *3*; Clark, *8*, *9*; Kastle, *27*). These ferments are sometimes distinguished by the production of a strong blue color in a tincture of guaiacum when used in the presence of oxygen or hydrogen peroxid (Haas and Hill, *16*, p. 383). Bailey (*5*) states that the activity of these oxidizing enzyms increases with the rise in temperature to a certain point, which may be called the optimum, and then decreases as the temperature is raised above this point. In almost every case, according to the same authority, the activity is entirely destroyed before a temperature of 100° C. (212° F.) is reached. He also states that the activity of these oxidizing ferments is diminished or destroyed by certain antiseptics and by other chemical substances. According to Asō (*1*, *2*), such substances as tannin, sodium fluorid, and sodium silicofluorid, interfere with the color reactions normally produced by oxidases. Bailey (*5*) notes the strong similarity existing between the oxidizing activities of these enzyms and the chemical reactions responsible for certain kinds of sap-stain, namely, post-mortem oxidation with change of color produced by solutions in contact with the air and the similar variations in the activity of the discoloring agency in relation to variations in temperature.

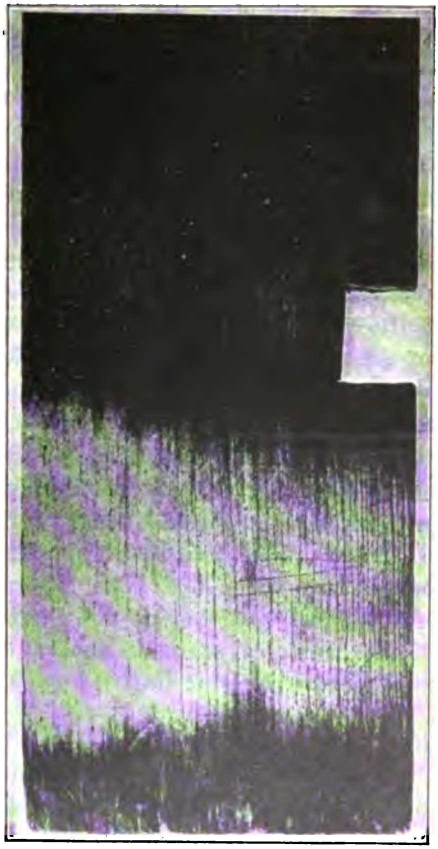

FIG. 1.—Board of sugar pine, showing chemical stain. The unstained area in the lower half of the illustration indicates the position of a crosser during the kiln treatment. The crosser afforded protection from oxidation. Photographed by H. D. Tiemann.

If discolorations in sapwood are due to the activity of oxidizing enzyms, which, as has been shown, are rendered inactive by exposure to a temperature of 100° C. (212° F.), a logical prophylactic measure would be the submersion of timber in boiling water. Bailey (*5*), during the spring of 1910, performed certain dipping experiments.

He found that when 1 by 3 by 6 inch boards of alder (*Alnus incana* Moench), white or gray birch (*Betula populifolia* Marsh), paper birch (*Betula papyrifera* Marsh), and various trees belonging to the rose family (Rosaceæ) were immersed in boiling water and then stacked under cover they would remain unchanged in color. Those boards which had been immersed in the boiling water and then placed in the most unfavorable conditions of high humidity and temperature in the open and exposed to the direct rays of the sun scorched on the surface. With the exception of this superficial scorching, no discoloration of the wood took place. On the other hand, untreated boards that had been cut from the same portion of the tree and subjected to similar conditions of temperature and humidity stained rapidly. Bailey (*5*) found that the rapidity and the depth to which the stain penetrates the wood varies with the temperature and the moisture, hot and humid weather being especially favorable for the production of stain. From a consideration of the results obtained, he concludes that sap-stain caused by oxidizing enzyms can be readily prevented by dipping the timber for a few minutes in boiling water.

Though chemical stains give more or less trouble in kiln-dried maple flooring and sugar-pine lumber, the discolorations may be prevented to an extent by the use of comparatively low temperatures (120° to 125° F.) and correspondingly low humidities (50 to 70 per cent; Tiemann, *51*, p. 185). Because of their limited distribution and the fact that they do not impair the strength or durability of the timber, chemical stains in general can hardly be considered as having very great economic importance.

FUNGOUS STAINS.

The second class of stains is produced by fungi. These fungi are disseminated by means of minute bodies known as spores. The spores may be produced in countless numbers and are blown about by the wind, washed along by the rain, or carried by animals, particularly insects. When, under favorable humidity and temperature conditions, they happen to lodge upon a substratum, such as the moist green sapwood of woods that contain the requisite food material, the spores may germinate and give rise to a mass of fine, usually septate threads, sometimes colorless at first, but often becoming darkened with age. This vegetative portion of the fungus is known as the mycelium, and the individual threads are called hyphæ. In some cases the hyphæ probably penetrate the wood but little, growing for the most part over the surface; in others, they may enter the sapwood through the medullary or pith rays. This does not result in the disintegration of the walls of the wood cells to any appreciable extent. The starches, sugars, and oils stored in the sapwood and pith rays, together with the contained air and water, probably exert an influence upon the advancing hyphæ and limit largely the growth of the fungus to the sapwood and the pith rays, where the sap-stain is mainly to be found. Practically no invasion of the heartwood takes place (Von Schrenk, *41*, p. 19). (Pl. I, fig. 3.)

THE SAP-STAIN FUNGI.

The relation of a fungus to the bluing of wood was first noted by Hartig (*17*, *18*). He describes the organism which causes the so-called "bluing" of conifers, especially dead or dying pine that has been injured by caterpillars, as *Ceratostoma piliferum*. He notes that it may also appear in damp firewood. According to Hartig, the brown mycelium very quickly penetrates the trunk through the medullary rays. He states that probably on account of the deficiency in moisture content the heartwood is avoided by the mycelium, whereas the sapwood often becomes quickly invaded and decomposed. Although described by Fries (*13;* see also Berkeley, *6*), who placed it in the genus Sphaeria, the fungus was later transferred by Fückel (*14*; see also Ellis and Everhart, *10*) to the genus Ceratostoma. Saccardo (*39*) still later divided the genus Ceratostoma and placed those species which possess colorless spores in a new genus, Ceratostomella. Winter (*58*), in a subsequent revision of the family included the fungus as *Ceratostomella pilifera* Fries under the new genus. It is now known as *Ceratostomella pilifera* (Fries) Winter (Engler and Prantl, *29*).

Figure 2 illustrates the fruiting bodies of this fungus. With the aid of a magnifying glass one may often see them clearly as stiff black hairs, approximately 1 millimeter (1/25th of an inch) in length,[5] swollen at the bases, and forming, en masse, a dark hairy covering on the ends and tangential surfaces of stained sapwood. These growths when well developed are sometimes referred to by lumbermen as "whiskers."

Many species of Ceratostomella have been listed by Saccardo (*40*). Though no reference is made to the fact, it is probable that a number of these stain wood.

The life histories of many species of Ceratostomella found on stained wood have been worked out by Von Schrenk (*41*), Hedgcock (*19*), and Rumbold (*37*) in this country and by Münch (*31*) in Europe. In connection with the study of several chromogenic fungi which discolor wood, Hedgcock developed in culture a conidial stage of Ceratostomella superficially resembling Cephalosporium. Münch and Rumbold associated a Graphium stage with the development of

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[5] In some species the length may exceed 2 millimeters.

Ceratostomella. During the extensive culture work of Hedgcock, however, extending over a period of four or five years and involving

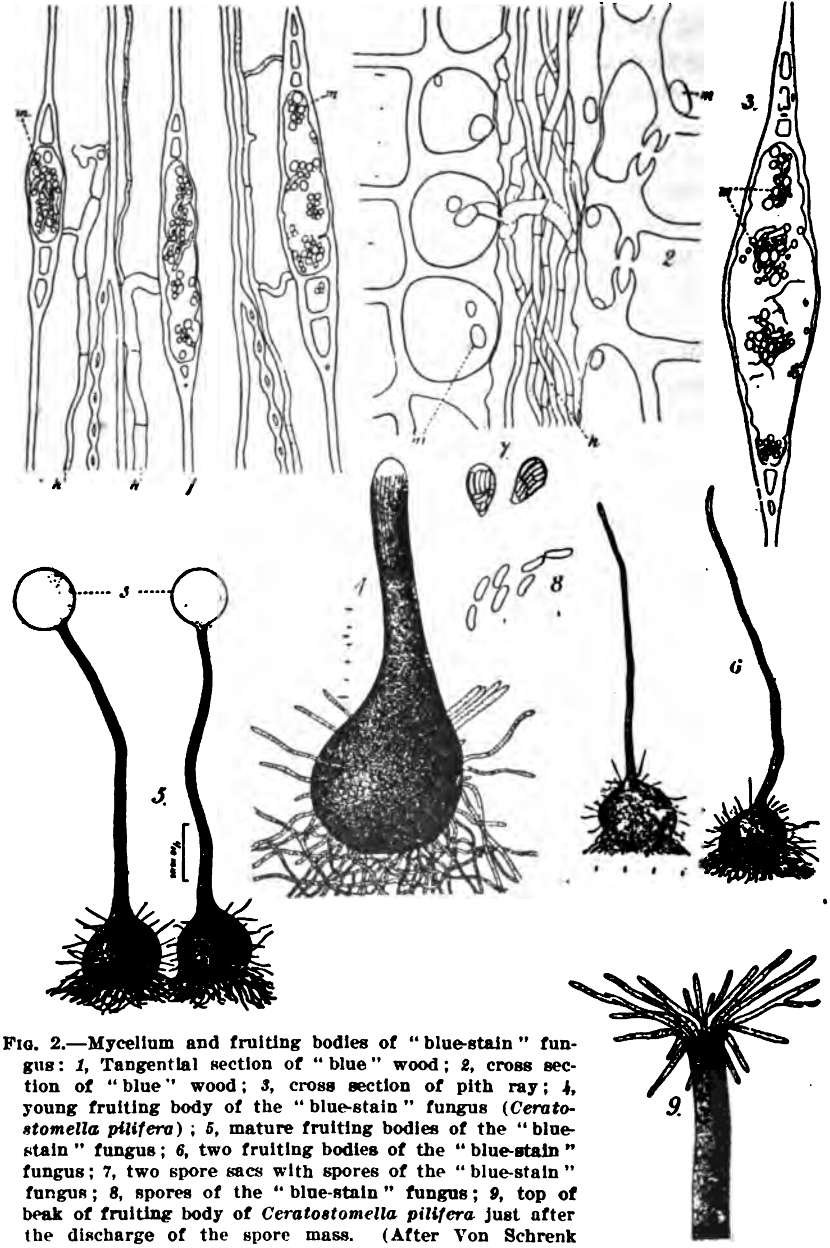
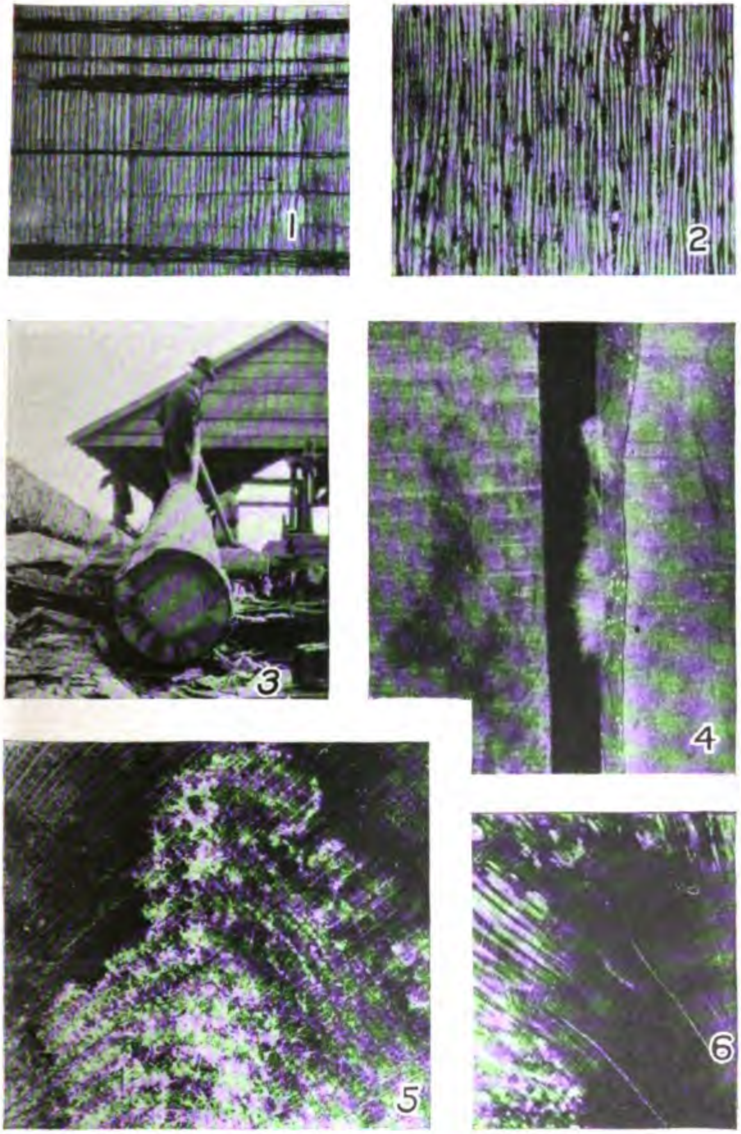


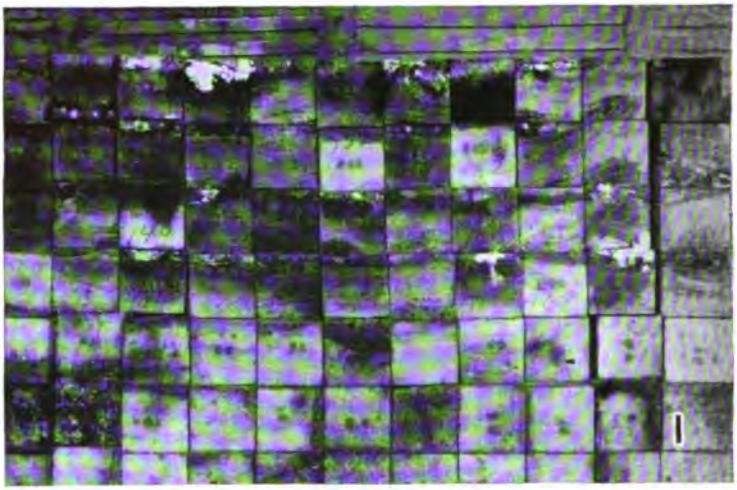
FIG. 2.—Mycelium and fruiting bodies of "blue-stain" fungus: *1*, Tangential section of "blue" wood; *2*, cross section of "blue" wood; *3*, cross section of pith ray; *4*, young fruiting body of the "blue-stain" fungus (*Ceratostomella pilifera*); *5*, mature fruiting bodies of the "blue-stain" fungus; *6*, two fruiting bodies of the "blue-stain" fungus; *7*, two spore sacs with spores of the "blue-stain" fungus; *8*, spores of the "blue-stain" fungus; *9*, top of beak of fruiting body of *Ceratostomella pilifera* just after the discharge of the spore mass. (After Von Schrenk (*32*), pl. 7.)

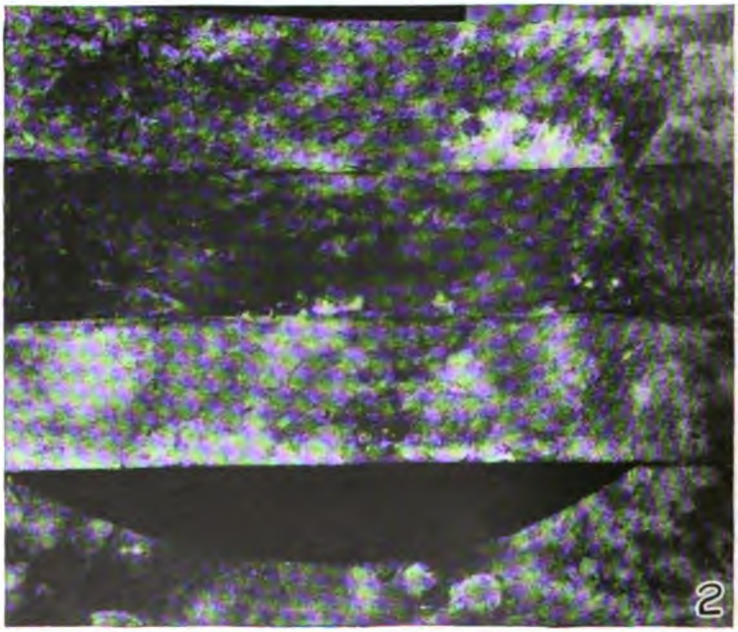
a number of species of Ceratostomella from a variety of sources, no Graphium stage of this fungus was ever reported.



EXAMPLES OF WOOD INFECTION.—I.

FIG. 1.—Radial section of bull pine, showing hyphæ of the blue-stain fungus growing in the pith rays. FIG. 2.—Tangential section of the same, showing many small hyphæ growing into the adjoining cells. FIG. 3.—Log of southern yellow pine containing sap-stain. FIG. 4.—Mycelium of mold growing between hard-maple boards in a kiln. FIG. 5.—Mold on the end of a sawed red-oak billet. FIG. 6.—Maple billet containing sap-rot, a condition brought about through the agency of wood-destroying fungi. The surface has been polished to show more clearly the bleached and disorganized condition of the sapwood. (Figs. 1 and 2 are from Von Schrenk (*41*), pl. 8; fig. 4 is from a photograph by H. D. Tiemann.)





EXAMPLES OF WOOD INFECTION.—II.

FIG. 1.—Artificially infected blocks of red oak and white oak in the tile chamber ready for the steaming experiments performed at the Madison laboratory. The large white areas of mycelium on the ends of the blocks in the upper four rows are wood-destroying fungi and probably developed as a result of infection in the log. FIG. 2.—Sawed felloes of oak (species not known). Note the abundant growth of mold which had developed in the material during shipment and while in storage. Photographed by H. D. Tiemann.

Hedgcock (*19*) identified the following species of Ceratostomella as responsible for the discolorations produced in certain woods:

C. pilifera (Fr.) Wint., in the sapwood of several species of pine (Pinus), fir (Abies), oak (Quercus), and ash (Fraxinus).

C. schrenkiana n. sp., in short-leaf pine (*Pinus echinata* Mill.).

C. echinella E. and E., in freshly cut heartwood and sapwood of beech (*Fagus atropunicea* (Marsh) Sudworth).

C. capillifera n. sp., in wood of red gum (*Liquidamber styraciflua* L.).

C. pluriannulata n. sp., in blue sapwood of red oak (*Quercus rubra* L.).

C. minor n. sp., in Arizona pine (*Pinus arizonica* Eng.).

C. exigua n. sp., in dead and dying trees of scrub pine (*Pinus virginiana* Mill.).

C. moniliformis n. sp., in red gum (*Liquidambar styraciflua* L.).

Münch (*31*) split up *Ceratostomella pilifera* Fries into a series of new species, as follows:

1 *Ceratostomella pini*, the important blue-stain fungus of pine.
2. The pilifera group, distinguished by the secondary fruiting bodies:
   (*a*) *C. piceae*, with an associated Graphium stage, possibly *Graphium penicillioides* Corda, in species of pine and fir.
   (*b*) *C. cana*, with an associated but unclassified Graphium stage. This species he also found in pine wood.
   (c) *C. coerulea*, having no associated Graphium stage.

With these species of Ceratostomella Münch includes two unrelated fungi, *Endoconidiophora coerulescens* and *Cladosporium* sp., as causing discolorations in coniferous timber.[6]

Von Schrenk (*41*), in his studies of the "blue wood" in dead and dying stands of the western yellow pine (*Pinus ponderosa* Laws.), found that the spores of Ceratostomella blown about by wind or carried by insects are often deposited in the exposed ends left by the breaking of branches or in the holes made by the bark and wood boring beetles. There, under the favorable conditions which usually prevail, they germinate and readily produce in a short time many colorless, branching hyphæ. The hyphæ grow into the bark tissues, then into the cambium, and from there into the medullary rays. With age the hyphæ take on a brown hue.

According to Von Schrenk (*41*. pp. 18, 19), "one of the first effects seen after the hyphæ have entered the medullary ray cells is the gradual solution of the walls separating the medullary ray cells from one another (fig. 2, *1*, *2*, *3*). The walls which separate the ray cells from the neighboring wood cells may become very thin, as shown in the middle ray (fig. 2, *1*), but they are rarely dissolved entirely. The intermediate walls, on the other hand, entirely disappear. This leaves a tube, with a cross section having the shape of the cross section of the ray, extending into the trunk from the bark. This tube is sometimes filled entirely with a mass of brown hyphæ, the larger number of which extend in the direction of the ray (Pl. I, figs. 1 and 2). From the ray cells some hyphæ make their way into adjacent wood cells (fig. 2, *2*; Pl. I, figs. 1 and 2).[7] They grow along these, both up and down (fig. 2, *1*), giving off branches to other wood cells. In this manner the whole wood body becomes penetrated by the brown hyphæ in a very short time after the first infection. The number of hyphæ in the wood cells proper, excluding the medullary ray cells and the cells of the wood parenchyma, is very small indeed. This is probably due to the fact that the fungus finds scant material upon which to live in the wood cells. The hyphæ are apparently able to puncture the unlignified walls here and there, but they stop at that point. The writer was not able to demonstrate that the hyphæ could attack the lignified walls. In other words, the 'blue' fungus is one which confines its attack to the food substances contained in the storing cells of the trunk and to the slightly lignified walls of these storing cells." According to the same authority (*41*, p. 19), the resin ducts may be attacked in like manner (fig. 2, *3*; Pl. I, fig. 2).

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[6] In a recent publication, C. J. Humphrey (*23*) describes a fungus, *Lasiosphaeria pezizula* (B. and C.) Sacc., as the cause of a blue-black stain in certain hardwoods, particularly beech and red gum. More detailed information concerning this fungus, as well as certain species of Ceratostomella, is given by E. E. Hubert (*21*).

In the case of sawed timber it is quite probable that the fungous spores falling upon the surface of the sapwood find there the moisture and food material necessary for germination. Subsequently they give rise to a mass of mycelium, many of whose hyphæ enter the wood through the exposed medullary or pith rays and then probably invade the surrounding tissue, as explained by Von Schrenk.

SUSCEPTIBILITY OF VARIOUS WOODS TO SAP-STAIN FUNGI.

The sapwoods of many kinds of timber are susceptible to sap-stain, though the degree of susceptibility varies considerably. Among the conifers southern yellow pine, western yellow pine, sugar pine, and the spruces seem to be readily stained and in the case of the broad-leaved trees, red gum, red oak, white oak, and hackberry seem to be particularly susceptible.

Often there is a considerable difference between a species when grown on the dry uplands and the same species when grown under the moist conditions characteristic of the lowlands (Von Schrenk and Spaulding, *44*). This difference in woods of the same species may be even more marked when grown in essentially different climates (Spaulding, *48*). It seems to be the opinion of many lumbermen that timber grown in the South is more susceptible to fungous attacks than timber grown in the North. If differences in susceptibility do exist in such woods it is difficult to state whether they are due to dissimilarities in mechanical structure, to the relative proportions of contained air and water, or to the variety and amounts of stored food present in the wood parenchyma and medullary rays. It is probable that differences in environmental conditions, i. e., temperature and humidity as affecting the growth of the fungi, are important factors directly responsible (Roth, *35*, p. 55–56).

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[7] E. E. Hubert (*21*) observed in the wood of scrub pine and northern white cedar hyphæ of *Ceratostomella* sp., which had penetrated tracheids and wood fibers for a distance of several cells from the medullary rays.

STRENGTH OF "BLUED" WOOD.

Since the wood fibers are not appreciably impaired by the growth of the blue-stain fungus, there should be no apparent loss in the strength of the invaded wood. Rudeloff (*36*) found that the compression strength of pine is not affected by the presence of bluing fungi. Tests on the stained wood of western yellow pine conducted at Washington University, St. Louis, Mo. (Von Schrenk, *41*) and later at the Forest Products Laboratory, Madison, Wis. (Weiss, *56*; Weiss and Barnum, *57*) proved that there is practically no diminution in the end compression or cross-breaking strength and hardness of the stained as compared with the unstained wood. In the case of heavily stained shortleaf pine, however, tested at the latter institution, there was found to be a slight decrease in the strength, toughness, and hardness as compared with unstained wood having the same moisture content. It may be safely stated that blued wood is practically as strong as unstained wood.

CAUSE OF THE COLOR IN "BLUED" WOOD.

The cause of the blue color in the wood has never been satisfactorily explained. R. Hartig (*17*, p. 66) ascertained that it arises from the presence of the brown fungous hyphæ in the intercellular spaces. According to Von Schrenk (*41*, p. 18, 25–26), it appears in the wood when the colorless mycelium begins to take on the brown hue characteristic of the mature fungus. Microscopic examination of the wood fibers taken from the blued wood reveals no indication of a blue color. While extracts of the blue wood with alcohol, ether, benzol, chloroform, alkalis, and acids differ in appearance from those obtained from clear wood, yet no blue tinge is apparent. Von Schrenk (*41*, p. 26) suggests that possibly "there is some pigment with a blue element in the 'blue' wood which is so faint that its detection in thin microscopic sections becomes almost impossible." Hedgcock (*19*, p. 110–111) states that "the brown color of the fungus apparently contains traces of a blue pigment whose color is transmitted by the wood cells of the pine more readily than the brown color." Münch (*31*, p. 3) concludes that the color is due to the arrangement of the mycelial threads in the wood. He cites, as somewhat similar examples, the blue color of thin milk, cigarette smoke, and the clear sky, wherein very fine particles are held in suspension in a transparent medium.

OTHER FUNGOUS ORGANISMS CAUSING SURFACE DISCOLORATIONS IN GREEN TIMBER.

In addition to the blue-stain fungi, there is another group, the molds, which commonly occur upon the freshly cut surfaces of green timber when stored under moist, warm, and stagnant conditions (Pl. I, fig. 5; Pl. II, figs. 1 and 2). Molds are occasionally found growing vigorously upon timber in kilns (Pl. I, fig. 4). This is especially noticeable when the atmosphere of the kiln is exceedingly moist or saturated and the temperature ranges from 90° to 110° F.[3] or from 110° to 130° F. (Tiemann, *51*, p. 186–187).

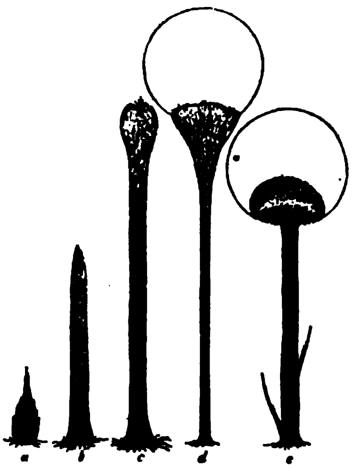

FIG. 3.—Fruiting body of *Graphium* sp. (After Münch, *31*.)

Hedgcock (*19*) showed that the blackening and browning so common in the green sapwood of pine (*Pinus* sp.), poplar (*Populus* sp.), tulip (*Liriodendron* sp.), red gum (*Liquidambar* sp.), oak (*Quercus* sp.), maple (*Acer* sp.), and several other woods can often be traced to species of Graphium. He cites:

G. ambrosiigerum n. sp., on Arizona pine (*Pinus arizonica* Eng.).

G. eumorphum Sacc., on wild red raspberry (*Rubus strigosus*) and related species.

G. atrovirens n. sp., on red gum (*Liquidambar styraciflua* L.).

G. smaragdinum (A. and S.) Sacc., on red gum (*Liquidambar styraciflua* L.).

G. rigidum (Pers.) Sacc., on red oak (*Quercus rubra* L.).

G. aureum n. sp., on white pine (*Pinus strobus* L.).

G. album (Corda) Sacc., on beech (*Fagus atropunicea* (Marsh) Sudworth).

Graphium spp. are perhaps best known by the upright, cylindrical, occasionally branched fruiting bodies 1 to 3 millimeters in height (fig. 3). These are often brown to black in color and bear at the tips comparatively large and, in many cases, confluent globules composed of masses of spores embedded in a mucuslike substance. These spore masses, though usually cream color, vary somewhat in hue, and in some species are tinged with gray, brown, green, yellow, or red. While these are the organs of fructification commonly observed, other types less conspicuous and bearing the so-called secondary conidia have been demonstrated in culture by Hedgcock (*19*).

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[3] Information from the section of timber physics, Forest Products Laboratory, Madison, Wis.

Other fungi mentioned by Hedgcock (*19*) as blackening wood are: *Alternaria tenuis* Nees., *Stachybotrys alternans* Bon., *Aspergillus niger*, *Chaetomium* sp., *Stemonitis* sp., *Gliocladium* sp., *Hormodendron* sp., *Hormiscium* sp., and *Cladosporium* sp. The apparent discoloration in these cases is due either to the presence of colored hyphæ in or upon the surface of the wood or to a luxuriant superficial growth of colored spore masses. In no case is it due to the secretion of any pigment which is absorbed by the wood.

Hedgcock (*19*) names three other species—*Penicillium aureum* Corda, *Penicillium roseum*, and a *Fusarium* sp. formerly included under *Fusarium roseum*—which, due to the secretion of soluble pigments, actually stain the wood red, purple, or yellow, according to the alkalinity or acidity of the medium. These stains are superficial, however, and readily dress off when the lumber is planed. Many other molds grow readily upon green sapwood and give the timber a displeasing appearance, though they cause no deterioration in the strength of the wood. From the material collected by the writer and sent to the Madison laboratory there have been isolated over 40 distinct species of fungi. With the exception of species of Ceratostomella and Graphium, together with a species of Fusarium which was identified by Dr. Mabel M. Brown, graduate student at the University of Wisconsin, as *F. arthrosporioides*, this number consists of fungi popularly known as molds. The determination of the molds was made by Dr. Charles Thom and Miss Margaret B. Church, of the Bureau of Chemistry, United States Department of Agriculture. They are listed below:

Aspergillus flavus series.
Aspergillus niger.
Aspergillus repens.
Aspergillus versicolor group.
Cephalothecium roseum.
Citromyces sp.
Cladosporium sp.
Clonostachys sp.
Gliocladium sp.
Haplographium sp.
Monilia sitophila.
Mucor sp.
Oidium sp.
Penicillium asperulum or *puberulum*.
Penicillium brevicaule series.
Penicillium commune.
Penicillium divaricatum.
Penicillium lilacinum.
Penicillium luteum.
Penicillium purpurogenum.
Penicillium roqueforti.
Penicillium rugulosum.
Penicillium solitum.
Syncephalastrum sp.
Trichoderma sp.

The great variety of genera and species here noted contains many earth dwellers and indicates that the molds commonly found upon green timber, especially during storage and transit, are for the most part soil forms whose spores have by accident fallen upon the moist surfaces of the sapwood and there found the conditions favorable for development.

It has generally been supposed that the growth of mold on wood is confined mainly to the surface or, at the most, to the superficial layers, perhaps a few cells in thickness. H. Marshall Ward (*55*), however, in connection with certain experiments upon spruce blocks which had been artificially infected with *Penicillium* sp., notes that the examination of sections from cultures 3 months old showed that the hyphæ of this fungus had entered the starch-bearing cells in the medullary rays of the sapwood and had consumed the starch. The hyphæ were observed deep in the wood extending from tracheid to tracheid through the bordered pits. Miss A. L. Smith (*46*) notes the presence of a dark-brown hyphomycete in decaying timber. This mycelium had invaded the woody tissue and had apparently brought about a partial destruction of the medullary rays (see also Freeman, 12).[9]

During a series of experiments by the writer, cultures were taken from various points within red-oak blocks 2½ by 2½ by 10 inches long which had been cut from green sapwood and then artificially infected with 15 different fungi including 13 of the common molds.[10]

The results obtained seem to confirm Ward's experiments, for positive mold cultures were secured even from the center of these blocks. However, as far as known, the molds do not cause any serious disintegration of the cell walls in green timber and thus do not impair the strength of the wood to any appreciable extent. As in the case of the blue-stain fungus, it is the stored food within the cells that is the object of attack.

The principal objection to the presence of mold lies in the discoloration due to the masses of mycelium and the luxuriant clusters of fruiting bodies which often develop upon green sapwood, and sometimes the heartwood, under conditions of high humidity and temperature resulting from poor ventilation. However, these superficial growths are readily removed during sanding or planing operations. In many cases they can be readily brushed off. This is particularly true of material which has become surface dried.

An inspection of a carload of moldy timber is quite likely to produce an impression that is liable to react unfavorably upon the shipper. Moreover, the presence of much mold or sap-stain in timber indicates the existence of conditions which are favorable to the development of decay. Such material, then, should be viewed with suspicion, but not of necessity with unfavorable discrimination.

FACTORS WHICH FAVOR THE GROWTH OF SAP-STAIN AND MOLD FUNGI.

The development of fungi is dependent upon four factors—a supply of air, containing the essential element oxygen; the requisite amount of moisture; a temperature range within certain limits; and the necessary food substances.

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[9] McBeth and Scales (*30*) list a considerable number of molds that are apparently able to destroy cellulose, though they act differently toward different kinds of cellulose.

[10] See page 29 for the list of fungi used in this experiment.

Air.—Fungi require oxygen for their growth. This is supplied as one of the constitutents of ordinary air. Even under storage conditions the supply is ample. Stagnant air containing a considerable amount of moisture is favorable to the growth of fungi in the timber, in that it prevents the drying of the wood. Timber entirely submerged in water is practically immune from fungous attacks, since the supply of oxygen is cut off.

Moisture.—The extent of the growth of sap-stain and mold fungi is largely dependent upon the amount of moisture present in the substratum. This moisture content in green timbers of different species as well as in the sapwood and heartwood of a particular species may vary considerably. Thus, according to Tiemann (*51*, p. 106; *33*, tables), the green sapwood of conifers may contain from 100 to 150 per cent moisture,[11] while the heartwood, probably being near its fiber saturation point, contains about 30 per cent. In the case of the hardwoods, both heartwood and sapwood may contain from 60 to over 200 per cent moisture. Frequently, however, there is present a greater quantity of free water in the sapwood than in the heartwood (Tiemann, *51*). In air-dried timber the amount of moisture may be reduced to anywhere from 8 to 18 per cent, according to the climate. In kiln-dried material it may be reduced to 3 to 15 per cent moisture, depending upon requirement and uses. This will explain why mold and sap-stain, so frequently found in green timber, are absent in thoroughly air-seasoned or kiln-dried stock. Air currents will often surface-dry the timber to an extent that will make it practically impossible for fungi to grow thereon.

The relative quantities of water and air found in the wood, according to Von Schrenk (*43*), are the most important factors in the control of the rate of growth and spread of the sap-stain fungus. He cites Münch's experiments (*32*) on artificially inoculated pine blocks,[12] differing only in the relative amounts of contained water and air. These experiments seem to indicate that the growth of the fungus is inhibited when the normal winter water content of the wood is raised to an amount that will insure a consequent reduction in the volume of contained air to at least 15 per cent, based on the volume of the fresh wood. According to Münch (*32*) an air content of 42 per cent, brought about through a reduction of the normal winter water content of the wood, is the optimum for development of the fungus in the wood. Münch (*31*, p. 59–62) states that the sap-stain fungus attacks recently felled trees, but does not penetrate deeply, owing to the high water content of the wood. He also states that the mycelium of the fungus readily penetrates throughout the sapwood of winter-felled wood when the loss in water content amounts to 10 to 20 per cent. Moreover, the growth in moist wood takes place for the most part in the older layers of the sapwood, or those in proximity to the heartwood. Finally, Münch concludes that the sap-stain fungus is capable of infecting the living tree, thus becoming parasitic, provided the fungous spores find entrance to the sapwood through injuries to the bark, such as those produced by bark-boring beetles; and that conditions favorable for fungous growth, namely, a reduction in the water content and a corresponding increase in the air content of the sapwood, are brought about through disturbances in the root system of the tree.

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[11] Unless otherwise stated, all percentages of moisture content are based upon oven-dry weight.

[12] The blocks in this case were artificially inoculated with the conidia of *Ceratostomella coerulea*.

In this connection certain investigations by Snell (*47*) on the relation of the amount of decay to the density of the wood should be mentioned. Five fungi which had been found to cause the rotting of structural timber in New England cotton mills were grown upon blocks of loblolly-pine sapwood and Sitka spruce. Several series of these blocks, each series containing a different percentage of moisture, were used in these experiments. The results obtained with loblolly pine agreed in the main with those of Münch (*32*) upon Scotch pine, a wood of about the same density. In the case of Sitka spruce, a wood of considerably less density, however, it was found that the limits of moisture content favorable for fungous growth were raised. In other words, "the values representing the upper limits for decay will vary inversely with the density of the wood."

Temperature.—It has been clearly demonstrated in a number of temperature tests[18] upon some of the molds derived from infected timber that these fungi grow readily between certain limiting temperatures. Beyond these, they cease to show any signs of activity. The optimum temperatures are commonly those which obtain during the late spring and summer months in certain parts of the country, particularly in the South, i. e., 80° to 85° F. It is probable, however, that each species has its own characteristic range.

Food.—Sap-staining fungi and molds have been shown in cultures to live upon quite a variety of foods. Being devoid of chlorophyll they can not, like the higher plants, manufacture their own food, but must depend upon that already available. The medullary rays and wood parenchyma of green sapwood often contain certain starches, sugars, and oils which represent the stored food of the tree. These are the substances upon which sap-staining fungi probably depend for their existence.

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[18] These tests were conducted at the Forest Products Laboratory, Madison, by Mrs. Rose Harsch Lynwalter.

When supplied with the essentials necessary for growth, fungi develop rapidly and often reproduce abundantly. Deprived of any or all of these factors, however, the vegetative portion, i. e.. mycelium, ceases to grow and eventually dies. In some cases, as, for instance, certain molds, the spores may retain their vitality for long periods under extremely unfavorable circumstances. When favorable conditions return, these spores soon germinate and often develop an abundant growth of mycelium within a few days. Fruiting bodies, sometimes bearing countless spores, may then make their appearance, and the life cycle is repeated. The ideal conditions for growth are often to be found in green timber containing a high percentage of sapwood when exposed to the stagnant atmosphere of the woods, poorly ventilated sheds, warehouses, and cars during warm, sultry, or rainy weather. Under such circumstances the sapwood may become thoroughly infected within a few days. Sap-stain may thus appear soon after infection with spores or mycelium of the sap-stain fungi. Wood-rotting fungi may also get a good hold upon timber under such conditions, and symptoms of incipient decay later become apparent (Pl. I, fig. 6).

DURABILITY OF STAINED OR MOLDED WOOD.

Since the blue stain and mold fungi cause little or no dissolution of the wood fibers, they do not affect directly the durability of the timber. If properly piled and dried, stained or moldy wood stock free from decay should not deteriorate further from the action of the fungi. However, the conditions which favor the development of sap-stain, mold, and sap-rot are much the same, namely, the presence of spores or mycelium of the particular fungi capable of producing these defects in wood, a substratum containing the requisite food material, moisture, and a high relative humidity (75 to 100 per cent), a temperature of 70° to 100° F., and a lack of circulation of the air, or stagnation, which retards or prevents the proper drying of the timber. There seems to exist among many lumbermen a false notion that mold and sap-stain represent early stages in the development of sap-rot, or "dote," as it is commonly called. While the presence of an abundant growth of mold or sap-stain in green stock indicates conditions which are likely to favor the growth of rot, it is well known that the rot is caused by a distinct group of true wood-destroying fungi which develop independently.

Molds in general develop rapidly. Hence, they may be often found growing profusely on green timber already infected with rot-producing fungi long before the latter have exhibited any noticeable evidence of their presence. It is possible, however, for wood destroyers to infect and bring about the disintegration of wood which contains no trace of mold or any other organisms.

LOSSES DUE TO SAP-STAIN OR MOLD.

INSANITARY PRACTICES IN THE HANDLING OF GREEN WOOD STOCK.

As a result of investigations in the woods, inspections of many carloads of green timber and dimension stock upon arrival at the mill, examinations of green and seasoned manufactured stock upon arrival at the vehicle factory, and talks with practical millmen and lumbermen, the writer is convinced that a considerable amount of the damage to vehicle stock, due to fungi, is brought about through the use of infected raw material. Many of the infections take place in the woods, as a result of insanitary practices in the handling of logs, bolts, and split billets. In many instances, during warm and humid weather logs and bolts have been allowed to lie in the woods for weeks. Under such conditions sap-stain is almost certain to follow. Moreover, the liability to attack by wood-destroying fungi is greatly increased.

Split billets, instead of being cross piled on dry foundations, are sometimes thrown carelessly about the stump and left until a convenient time for hauling arrives. Under favorable circumstances it takes but a few days for certain fungi to gain a good hold on such stock, and unless later checked or destroyed by some process such as kiln drying, they may produce a permanent stain or decay in the sapwood.

It is quite probable that a serious shortage of cars suitable for handling the logs, bolts, and billets may prevent at times the rapid movement of raw stock to the mills. This results in the accumulation of material in the woods and railroad yards and contributes to conditions in many cases favorable to the development of the fungi. Frequently box cars are used where in normal times the more open and consequently better ventilated types of car would be employed.

Failure to observe proper measures during storage, such as the use of dry foundations for logs and bolts, the cross piling or stripping of billets on dry foundations sufficiently high to give suitable ventilation from beneath, and the storage of stock in properly ventilated sheds, has furnished conditions suitable for the development of mold, sap-stain, and decay in such material.

A few millmen seem to have the mistaken idea that an abundant growth of mold on green stock serves to protect it from checking by preventing evaporation from the surface of the wood and actually absorbing, or possibly condensing, moisture from the surrounding atmosphere and then transmitting it to the wood. The fungus derives its moisture from the wood, not the air. Its presence, however, often indicates a high humidity in the immediate vicinity, a condition which prevents the drying of the wood and thus favors the growth of fungi. It is quite probable that the phenomenon known as guttation, i. e., the collection of minute drops of excreted water upon the fungous growth, is responsible for the misconception.

In some instances split billets upon being unloaded from the cars are thrown in a pile beside the track, sometimes upon damp soil, there to remain for perhaps a month or until opportunity can be found for removal to storage sheds. Losses due to fungi are a natural consequence of such treatment.

It has taken time for those unaccustomed to the handling of green stock to work out satisfactory methods which would provide proper ventilation of dimension, sawed, or turned stock during transit. Meantime, many shipments have been seriously damaged. Of the different forms of stock, the sawed billet, the rim strip, and plank have given the most trouble. Losses are not confined to such stock, however, for turned spokes and hubs, unless properly safeguarded during transit, are liable to stain and mold.

Sawed billets often arrive at the factory in a badly stained condition. It is probable that material containing fungous infections sometimes finds its way into their manufacture. The squared surfaces lend themselves to close piling and thus to the formation of masses wherein sufficient ventilation is impossible. Rim strips also frequently become badly stained while in transit, as a result of the same causes, together with the fact that some manufacturers require such stock to be close piled in closed box cars and even sprayed with water to prevent checking. It is unfortunate that the conditions necessary for the prevention of checking in green stock are as a general rule favorable to the growth of fungi, and vice versa.

ECONOMIC IMPORTANCE.

The presence of much sap-stain and even mold in timber is considered by some lumbermen as a defect. Therefore, degrading of material thus affected, with consequent loss in monetary value, may result. Such unfavorable discrimination is due to the notion that stained or moldy material is not as sound as clear stock. In the case of molds, it is an easy matter to remove the surface blemish by the simple process of sanding or planing. With sap-stain, however, the removal of the discoloration depends entirely upon the depth to which the mycelium has penetrated. In some cases the stain may extend to the heartwood. It is evident that it can not under such circumstances be removed by the processes referred to.

The presence of much stain will prevent the use of timber for purposes where color, texture, and clearness of grain are of prime importance. Basket and box veneer, interior finish, flooring, and furniture stock which are to have no protecting coat of paint must be free from stain. Discrimination, however, should not be made against sap-stained or moldy stock that is to be covered, provided there is no incipient decay associated with it.

The reduction in the value of stained lumber sometimes amounts to $2 or more per 1,000 feet, board measure, and perhaps one-fourth of the annual mill cut of the United States is attacked. In one year it was estimated that the total losses from sap-stain amounted to between 8 and 9 million dollars (Weiss, *56*; Weiss and Barnum, *57*; see also Pratt, *34*). The amount in any locality, however, depends upon the climate, the season, and several other factors.

Weather conditions have a marked influence upon the amount of damage to freshly cut timber in the woods or to green stock in storage and in transit. During warm and moist weather such stock will sometimes stain badly and in a short time, unless it is properly safeguarded. This, of course, is due to the fact that the warm and humid conditions stimulate the development of the fungi. It follows, then, that the greater losses from sap-stain, sap-rot, or mold should be expected during the warmer months, and especially during those months in which both high temperatures and high humidity normally prevail. As a matter of fact, this is the case. In the months of April, May, June, July, and sometimes August and even September, depending upon climatic conditions, the greatest damage occurs. In the South, owing to the prevailing high temperatures and relative humidities, the losses are often extremely severe. The greatest losses occur in low-grade coniferous lumber, especially the southern pines, owing partly to the high percentage of sapwood and partly to the fact that the low-grade lumber is seldom kiln dried, but is stacked in the yard to air season. Under such circumstances, unless unusual precautions are observed, it is very liable to the attacks of the sap-stain fungi.

From replies to the questionnaires sent out by the wood-stock committee to contractors and producers of wood stock regarding sap-stain and mold in vehicle stock and from the data derived from the personal investigations of the writer, it was learned that these losses are dependent largely upon the manner in which the stock is piled in the cars and sheds during transit or storage. The losses average less than 10 per cent, but may reach from 25 to 75 per cent. The writer was informed that because of such damage to green spokes during the summer of 1918, sometimes as many as 50 per cent in a carload lot were culled. When turned spokes were selling at $150 per 1,000 feet b. m., the loss on a carload containing perhaps 12,000 escort spokes, 2½ by 2½ by 27 inches, was evidently considerable, perhaps amounting to hundreds of dollars. One firm reported that it had knowledge of entire carloads being destroyed. In some instances cars had gone astray and had finally reached their proper destina-

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tion after one or two months on the road. Losses in those cases were often practically complete. Sixteen different firms reported that for the year 1917 their individual losses due to "heating in transit," as staining is sometimes explained by lumbermen, varied from $100 to $5,000. One company reported the losses as varying from $25,000 to over $75,000 in different years.[14]

CONTROL MEASURES.

A great many attempts have been made to devise measures for the control of sap-stain and mold in green timber. With the exception of kiln drying, however, none of these has proved entirely satisfactory. When tried under circumstances unfavorable to the growth of fungi, some of these measures have met with considerable success, but when put to the test under conditions which stimulate fungous development, they have often failed. For the most part they have been prophylactic rather than curative in nature. However, it is believed that many of the following measures, although not entirely effective, will assist materially in reducing losses due to sap-stain, mold, and incipient decay in green stock.

HANDLING IN THE WOODS.

AUTUMN AND WINTER CUTTING.

Many lumbermen (*15*) think that, where possible, timber should be cut in the autumn and winter. While this is probably true, the reason often given is incorrect. The statement is usually made that winter cutting is better because the "sap is down." It has been shown by T. Hartig (*33*, tables; Janka, *26*) that during the spring when the growth is most active the tree sometimes contains less water than in the winter. It is probable that the changes in moisture content which do take place are confined mainly to the sapwood. It is true that the movement of sap is much more rapid at the time of active growth and that there are important chemical changes which take place therein during the different seasons of the year. In the winter, insoluble starches and gums are stored in the sapwood. During the spring these are changed to soluble sugars and are borne through the living tissues. The sapwood of summer-cut logs, therefore, contains soluble foods which render it extremely susceptible to attacks by fungi during the warm months when these organisms are most active. Winter-cut logs, on the other hand, have an opportunity to season under conditions less favorable for fungous growth and by the time warm weather arrives will have dried to a degree which will render them less susceptible to fungi (Roth, *35*, p. 57).

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[14] National Implement and Vehicle Association and other Vehicle and Vehicle Parts Manufacturers. Information Division of the Wagon and Vehicle Committee and the Wheel Manufacturers' War Service Committee. Wood Stock Committee. Sap-stain and mold in transit. Nat. Implement and Vehicle Assoc., etc., Bul. 30, 5 p. 1918. A. B. Thielens, chairman. Typewritten.

In the bottom lands of the South, however, autumn and winter cutting may not always be feasible owing to the wet and muddy conditions then prevailing, which make hauling difficult, if not impossible.

Incidentally, leaf seasoning (Tiemann, *51*), i. e., girdling trees while in full leaf and then allowing them to remain, often for years or until the leaves have entirely shriveled up, with the idea that much of the free water in the sapwood will be drawn off by transpiration through the leaf surfaces and thus prevent sap-stain, does not seem to be practiced in the regions visited by the writer. Although this method is said to be common in the seasoning of teak in India and has been advocated by some as applicable to gum in this country, yet it does not seem to meet with general approval, because it exposes the timber to the ravages of insects and to fungi causing decay.

RAPID HAULING.

One of the precautionary measures to be observed, especially during the late spring and summer, is that of hauling timber immediately after felling. Raw stock can not be gotten out of the woods and to the saw too rapidly. It is possible for fungous infections to take place at all times of the year on the exposed surfaces of freshly cut timber. These develop more rapidly, however, during warm, humid weather, and especially under the conditions which obtain in the woods.

STORAGE IN THE WOODS.

If it is found necessary to allow logs and bolts to remain in the woods, they should be so separated that the ends are left several inches apart. If the sawed ends remain in contact, fungi are liable to develop between them. Some have recommended that logs that are to remain in the woods during the summer be painted on the exposed ends with creosote (Von Schrenk, *42*). It has been considered advantageous by some (Von Schrenk, *42*; see also Hartig, *18*) to remove the bark from logs that must of necessity be left in the woods for an extended period. Advocates of such treatment state that the peeled surfaces soon become air-dried and consequently provide insufficient moisture for the germination of any fungous spores that may fall thereon. In order to keep such logs off the damp ground and thus assist in the air-drying process measures must be taken to provide some sort of temporary foundation free from stain, mold, or rot.

When it becomes necessary to store split billets in the woods, they should be piled with only two billets in a course and should rest upon a foundation located on dry ground and consisting, where possible, of billets of split heartwood free from rot.

HANDLING RAW STOCK IN TRANSIT.

TYPES OF CARS.

In shipping green stock to be used in the manufacture of vehicles, etc., the following types of cars have been preferred:

Flat cars	logs (fig. 4).
Gondolas or stock cars	bolts (fig. 5).
Stock or vegetable cars	split billets or dimension stock.
Ventilated box cars	lumber or dimension stock.

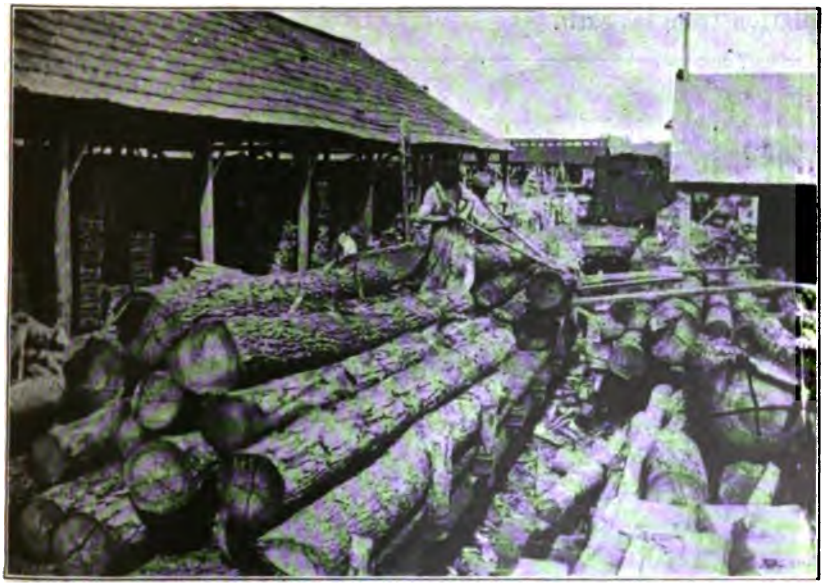

FIG. 4.—Unloading logs from a flat car. This is the type of car usually used for the shipment of logs.

PROVISIONS FOR THE PROPER VENTILATION OF STOCK IN TRANSIT.

Well-ventilated types of cars should be selected where possible, if staining and molding are to be prevented (figs. 4 to 10). Preparatory to use, these cars should be thoroughly swept free from rubbish, damp sawdust, lime, or manure. In the case of box cars, it is important that the roofs be carefully inspected to make sure that they are water-tight. If it becomes necessary to use box cars for the transportation of split billets during the late spring and summer months, it is suggested that the billets be ricked and that strips or occasional crossers of the same stock at intervals of 12 to 16 inches be used to assist in the ventilation of the pile. Side doors should be open and both doorways boarded up, leaving at least 1½-inch spaces between the boards. If box cars are equipped with small end doors of the ventilating type, these doors should be left open and the doorways cleated to prevent the stock from working out during transit. Lumber shipped in box cars must be stripped.

HANDLING RAW STOCK IN THE YARDS.

STORAGE OF LOGS AND BOLTS.

When piling or cording logs and bolts in the yard for storage, it is important that they be kept off the ground by the use of clean skids or permanent foundations of seasoned fungus-free planks, stone, or cement. Such foundations should be placed on well-drained soil free from underbrush or weeds that might interfere with proper ventilation from beneath.

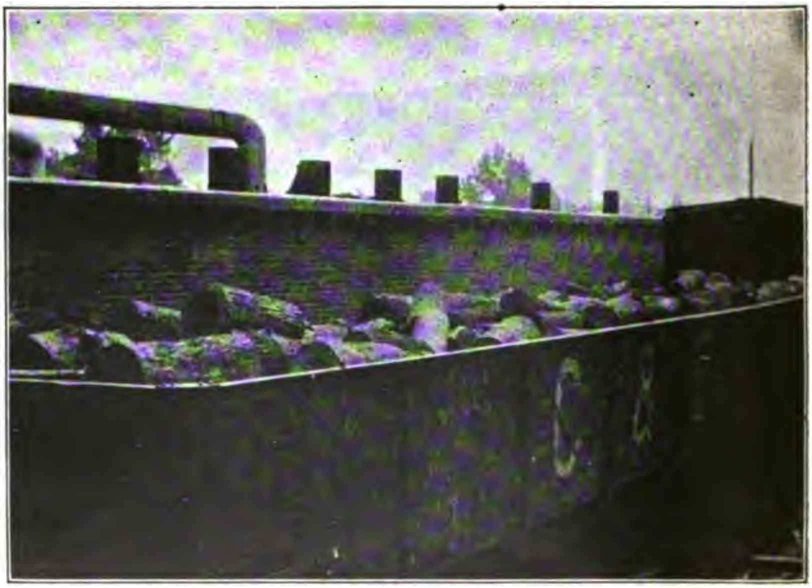

FIG. 5.—Bolts loaded in a gondola car. Gondolas, stock, or vegetable cars are best adapted to the transportation of this type of raw stock.

STORAGE OF BILLETS.

Billets that are not turned at once should be stored upon dry foundations and in properly ventilated sheds (fig. 11). When sufficient storage space is available, the method of piling used by one of the large wheel manufacturers in the North, shown in figure 12, is recommended.

STORAGE OF GREEN LUMBER.

The methods of piling lumber are pretty well understood and need little explanation here (7).[15] In general, it is well to select a location on well-drained soil free from weeds and one which will allow the prevailing winds to blow through the sides rather than upon the ends of the stacks.

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[15] For information concerning this point, the reader is referred to Bulletin No. 552, United States Department of Agriculture (7), copies of which may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents per copy.

Care should be taken to provide suitable foundations consisting of metal or well-seasoned heart stock, preferably creosoted and resting upon piers of creosoted wood or, better, of stone, brick, concrete, or metal. All foundations should be sufficiently high to allow for ventilation vertically through the stacks. Moreover, there should be ample space between the stacks to permit a free circulation of the air around them. Finally, it is important that narrow strips, perhaps 1 inch wide and at least 1 inch thick, of well-seasoned, kiln-dried, or chemically treated wood be used between all courses and that they be carefully placed in vertical alignment to prevent warping of the stock.[16]

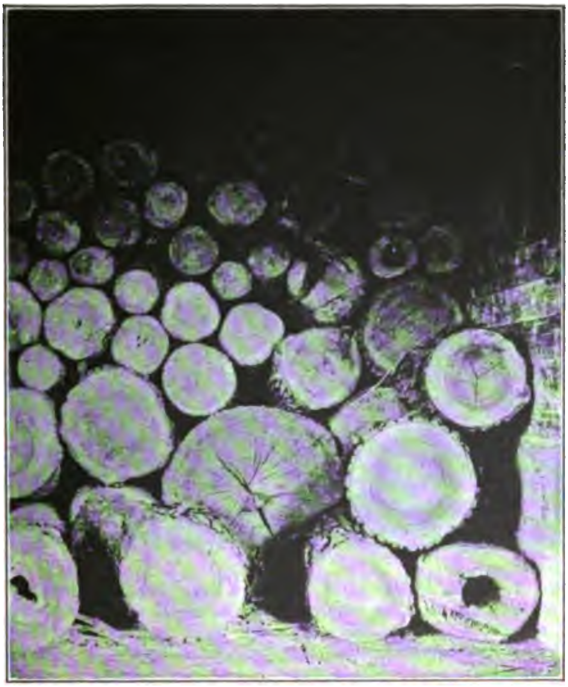

FIG. 6.—Bolts piled in a box car. Note the débris on the floor of the car. Bolts are likely to suffer from fungous attacks when shipped in box cars with the doors closed.

HANDLING AT THE MILL.

EARLY MANUFACTURE.

Logs, bolts, and split billets should be sawed into dimension stock or planks and manufactured as soon as possible. This will do much toward safeguarding the material by reducing the time in storage.

AIR SEASONING.

Provided kilns are not available, the dimension stock should be seasoned from six months to a year or more, depending upon the size and kind of material.[17] When sufficiently dry, shipments in closed box cars will suffer little or no loss from sap-stain or mold. In all cases where air seasoning is resorted to, unless great care is exercised in providing for ample circulation of air through the stock by such means as open piling, fungous and insect troubles are likely to develop. It is absolutely necessary to strip or cross pile the stock upon dry foundations. For purposes of stripping, kiln-dried or chemically treated strips 1 inch wide and at least 1 inch thick should be used between courses. All sheds for the storage of this material should be dry and well ventilated.

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[16] The general sanitation of lumber yards and the proper methods to be observed in the piling of timber to prevent or reduce losses in storage due to fungi, together with a consideration of the more common rot-producing organisms, are clearly described by Humphrey (22), in Bulletin No. 510, United States Department of Agriculture. Copies may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 20 cents per copy.

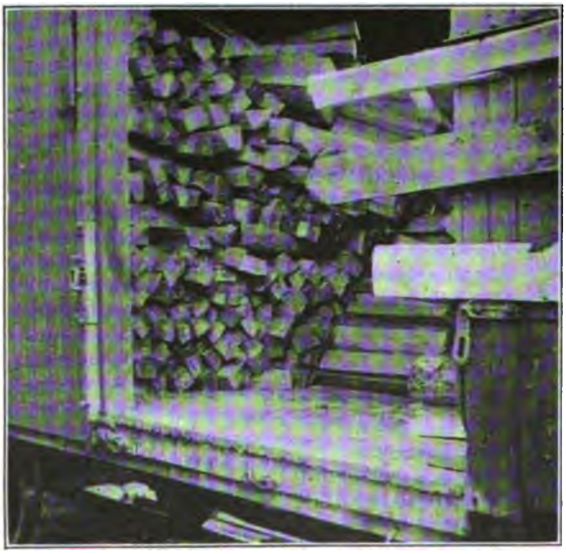

FIG. 7.—Split billets piled in a box car. When occasional billets are used as crossers and the doors of the car are cleated open this type of spoke stock suffers but little while in transit.

KILN DRYING.

By far the most effective and quickest method of treating green stock, as a prophylactic measure, to destroy fungi or insects and to reduce shipping weight, is to subject the material to proper kiln drying. When producers are equipped with, or have access to, modern kilns operated on a scientific basis and are so situated that stock can be moved rapidly, less concern need be given to fungous troubles. Kiln-dried spokes can be bundled or close piled in dry warehouses or in ordinary box cars and shipped without loss.

Material kiln dried directly from the saw has been shown to be just as good as air-seasoned stock (Tiemann, *51*, p. 300) and in many cases much better as far as strength, toughness, and freedom from defects are concerned. Moreover, the time necessary for seasoning can often be reduced from one year to three weeks or from three to five years to as many months.

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[17] The reader is again referred to Department Bulletin No. 552 (7) for information concerning the seasoning of wood.

Kiln drying reduces shipping weight; makes the lumber fit for almost immediate use; eliminates or reduces losses due to insects,[18] or to checking, rotting, staining, or molding; improves the quality of the lumber; reduces the amount of yard space; and saves the tying up of capital and carrying costs (Tiemann, *51*, p. 4, 5).

It is possible that where several producers are located within a few miles of one another, a battery of modern dry kilns, operated according to the most approved methods (possibly on the community plan) might solve the problem of cost of installation and operation.

In dry kilns, stripping or cross piling the stock and providing means to prevent stagnation of the confined air are absolutely necessary if the development of mold is to be avoided. The water spray kiln devised at the Forests Products Laboratory represents one of the latest developments in the temperature and humidity-controlled type of kiln.[19]

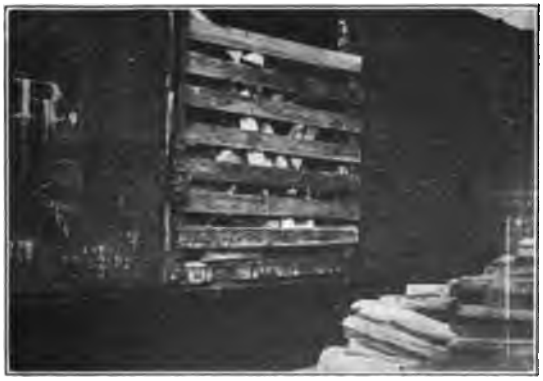

FIG. 8.—Split billets loosely piled in the areaway between the doors of a box car. The doorways are loosely boarded up to allow for ventilation of the car and at the same time prevent the stock from working out while in transit.

During the first few weeks of kiln drying, when the humidity is high and the temperature ranges from 80° to 105° F., an abundant growth of white mycelium occasionally forms between the courses and interferes more or less with the circulation of the air in the kiln. This is due to the presence of mold fungi, and it usually indicates stagnation in the kiln (Pl. I, fig. 4). Steaming for one hour at a temperature of 160° to 180° F. has been found effective in destroying or at least checking the growth of this mold (Tiemann (*51*), p. 187).

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[18] Powder-post beetles, however, are said to cause considerable damage at times in seasoned stock; in fact, these beetles do not work in green stock.

[19] A complete description of this kiln is given in Bulletin No. 509, United States Department of Agriculture (*52*), a copy of which may be procured from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 5 cents. Further information concerning the design and installation of this kiln is given in Bulletin No. 894, United States Department of Agriculture (*50*), to be procured from the same source at 10 cents a copy.

STEAMING GREEN STOCK AS A CONTROL MEASURE.

METHODS COMMERCIALLY EMPLOYED.

Steaming certain kinds of stock (green gum lumber, birch hubs, spokes, and sawed felloes of red or white oak) is sometimes resorted to as a means of reducing shipping weight by hastening drying or to even up the color and reveal defects in the wood.

In the steaming of green gum lumber a large steel tank, or preparator, is employed. The lumber loaded upon trucks is run into this preparator and steamed for perhaps 15 to 30 minutes at pressures of 20 to 30 pounds (figs. 13 and 14). Provided this lumber is then carefully open piled, it remains clean. When close piled or when exposed to adverse weather conditions, however, it may mold almost as readily as untreated green lumber.

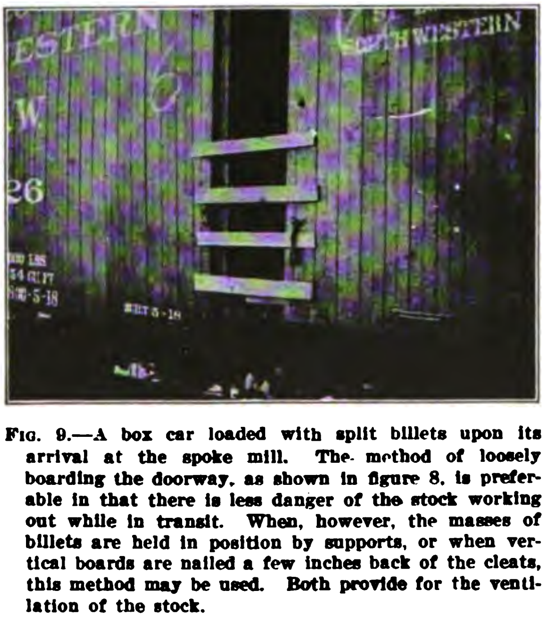

FIG. 9.—A box car loaded with split billets upon its arrival at the spoke mill. The method of loosely boarding the doorway, as shown in figure 8, is preferable in that there is less danger of the stock working out while in transit. When, however, the masses of billets are held in position by supports, or when vertical boards are nailed a few inches back of the cleats, this method may be used. Both provide for the ventilation of the stock.

Hubs, sawed felloes, and turned spokes green from the saw are sometimes steamed at atmospheric pressure. At one plant visited, green birch hubs were stacked in large cement boxes and subjected to exhaust steam for 24 to 36 hours, depending upon the size of the hub. At the end of that time the steam was shut off and the hubs were allowed to cool for perhaps 10 hours. The hubs were then carried to a ventilated warehouse and stacked, zigzag fashion, to provide for ample circulation of the air through the inside as well as around them. In this manner an even drying was secured. Two to three weeks was considered a sufficient length of time for the necessary air drying previous to shipping. During the warmer months, stock cars were used as means of transportation.

The steaming of gum and birch is a comparatively simple process. But in the case of woods that check readily, such as oak, this treatment requires considerable care.

THE EXPERIMENTAL STEAMING OF RED-OAK AND WHITE-OAK BLOCKS AT THE LABORATORY OF FOREST PATHOLOGY, MADISON, WIS.

During the spring of 1919 the writer performed several series of experiments at the Madison laboratory to determine the efficiency of steam at atmospheric pressure in destroying mold and sap-stain fungi in artificially infected red or white oak blocks 2½ by 2½ by 10 inches. Incidentally the rate of drying and the amount of checking were noted in connection with the steaming.

The blocks were sawed from the sapwood of summer-cut logs, weighed, and then sprayed with a water suspension of spores taken from cultures of mold fungi originally derived from infected material sent in by the writer. A list of the fungi used in these experiments follows:

Aspergillus flavus.
Aspergillus niger.
Cephalothecium roseum.
Ceratostomella sp.
Citromyces sp.
Graphium sp.
Monilia sitophila.
Mucor sp.
Penicillium asperulum.
Penicillium divaricatum.
Penicillium luteum.
Penicillium pinophilum.
Penicillium rugulosum.
Syncephalastrum sp.
Trichoderma sp.

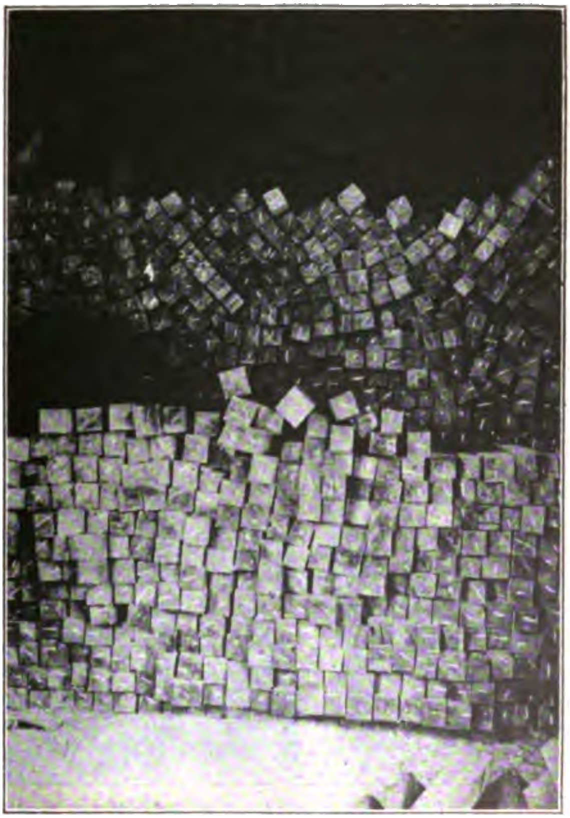

FIG. 10.—Square billets close piled in a box car. This type of raw stock suffers considerably when piled in the manner shown here. Stripping or cross piling while in transit or storage is essential if losses from fungi are to be avoided.

The sprayed blocks were then placed in a tile chamber, which served as an incubator. After several weeks in this chamber, where an average relative humidity of 95 per cent and an average temperature of 70° F. prevailed, the blocks became well infected and developed countless numbers of the fruiting bodies peculiar to the fungi mentioned above (Pl. II, fig. 1).

A steam box was constructed of cypress, equipped with thermometers, dew-point apparatus, and manometer and connected with the main which supplies steam to the laboratory greenhouse (figs. 15 and 16). By means of suitable reducing valves in the connecting pipes it was possible to control the steam pressure in the box; hence, the exact conditions to which the blocks were subjected could be readily determined. Steam at atmospheric pressure only was used.

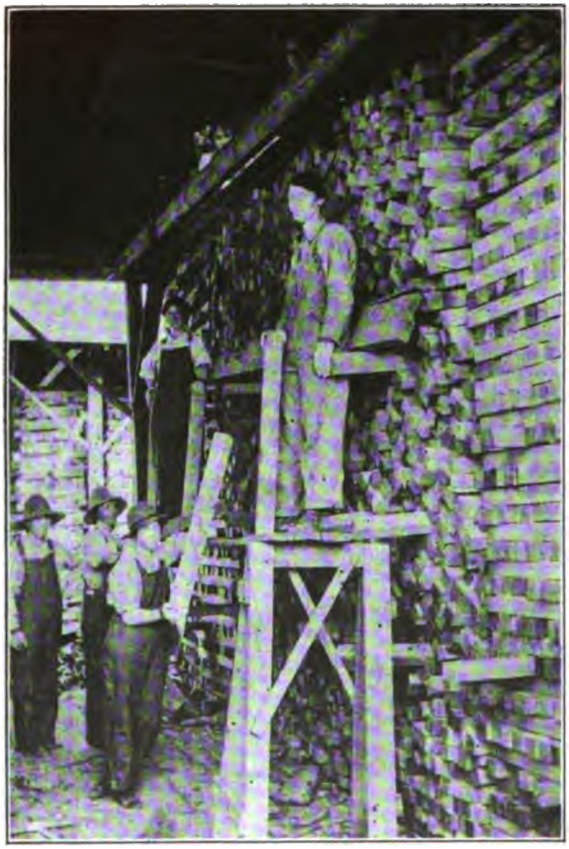

FIG. 11.—Stacking sawed billets in an open shed. It will be observed that the billets at the extreme right are cross piled, while those in the center are close piled. The former method of piling insures a better ventilation of the stack, provided intervals of at least 1 inch are left between the adjacent billets of a course. In the case of the cross-piled billets shown here this provision was not made.

Previous to steaming, the blocks were again weighed. They were then close piled or stripped in groups of 25 in the steam box and steamed for different lengths of time. At the end of the steaming period, some of the lots were allowed to cool for a certain time and then reweighed. Others were weighed immediately. Nearly all were put in a small ventilated box in the open and allowed to air-dry for several weeks. Some, however, were placed in a closed shed for four weeks, and still others were taken from the steam box, weighed, and placed directly in the tile chamber. Some lots were stripped; others were close piled. An interval of at least 3 inches was maintained between adjacent piles.

After the preliminary seasoning mentioned above, a number of the blocks were returned to the tile chamber for incubation. This was done for the purpose of subjecting the blocks to the conditions existing in box cars and poorly ventilated warehouses during warm and

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sultry weather. The tile chamber, when given a preliminary treatment, which consisted of intermittent steaming for three successive days to reduce the amount of viable fungous growth therein, provided these conditions admirably. In this chamber the temperature was maintained at an average of 85° F., while the relative humidity varied from 70 to 95 per cent. At the end of four weeks in the tile chamber the blocks were removed and their condition with respect to molding noted.

The following observations were made from several series of experiments:

The amount of drying which took place in the steam box was comparatively slight. This seemed to depend, however, upon the relative moisture content of the wood previous to steaming. Green blocks usually lost, while partly seasoned blocks often gained in weight.

Beyond a certain length of time, dependent upon the moisture content of the wood and the surface area of the blocks in relation to volume, there seemed to be little gained, in so far as the reduction in weight was concerned, by continued steaming. Six or nine hours' steaming seemed to be no more efficient than three hours in the case of the 2½ by 2½ by 10 inch blocks.

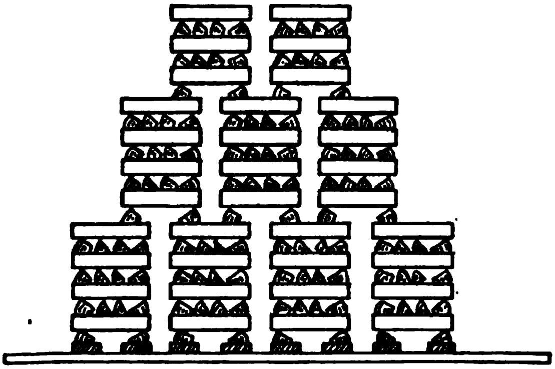

FIG. 12.—Diagram illustrating one method of stacking green split billets. This method is used by one of the large wheel factories of the North. When ample storage space in well-ventilated sheds is available, this method is recommended.

Steamed blocks subsequently dried more rapidly than those that were simply air-dried.

Open piling or stripping in the steam box was preferable, in that it permitted a better circulation of the steam in the box and thus insured a more uniform treatment of the blocks.

The amount of checking varied in the several lots when steamed under the same conditions. This may have been due to the fact that the blocks differed considerably in the relative proportion of sapwood and heartwood present.

The greatest amount of checking occurred in those lots that were subjected to rapid cooling and surface drying by exposure to air currents from open doors and ventilators. Blocks allowed to cool in the steam box with doors closed seemed to suffer least in this regard. Slow cooling was, in some cases, brought about by opening a small hatch in the roof of the steam box at the conclusion of the steaming period.

The total amount of checking which had taken place in the steamed blocks, both during the steaming process and the subsequent period of air seasoning, extending over four months, exceeded but little that noted in those blocks which had been simply air seasoned for the same length of time.

Steaming seemed to be effective in killing the fungi in the infected blocks when employed for a period of three hours. Cultures taken from various points in or upon the blocks by means of a sterile scalpel and needle gave no growth, while cultures taken from check blocks which had not been steamed gave positive results in every case.

Steamed material, unless open piled under conditions which insured an ample supply of circulating air, molded almost as readily as green stock.

Steamed blocks that were given a month's air drying subsequent to steaming and previous to storage under the extreme conditions that prevailed in the tile chamber showed a little more resistance to the invasion of fungi than those blocks that were placed in the tile chamber immediately after steaming.

It is quite probable that the steam treatment of wood stock, followed immediately by prolonged submersion of the material in some of the antiseptic solutions to be described later, might prove to be a fairly effective method for the control of fungi in infected stock. This treatment might be applied to special classes of wood stock where the margin of profit would justify the extra cost.

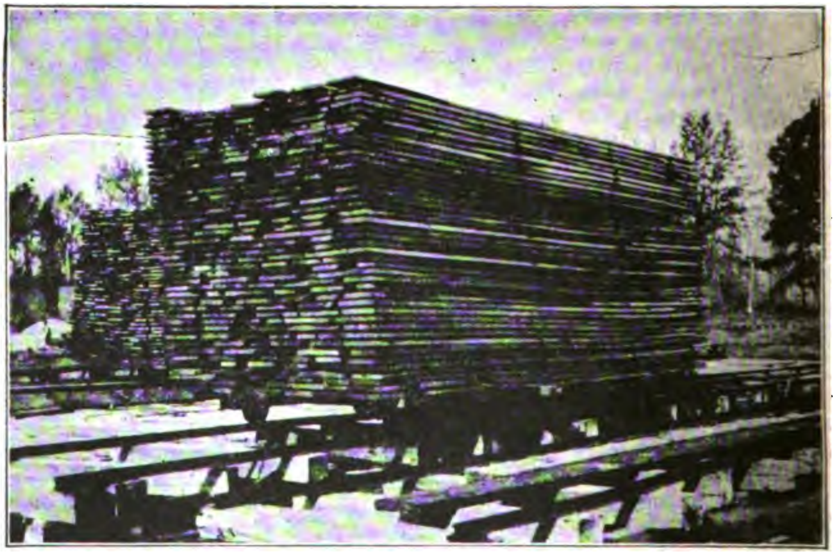

FIG. 13.—Boards of red gum loaded on a truck and ready to be rolled into the preparator (shown in fig. 14).

THE CHEMICAL TREATMENT OF GREEN WOOD STOCK.

Many attempts have been made to find some chemical compound or mixture that, when applied as a dip, will control sap-stain and mold in green timber. A great many substances have been tried, but none have proved entirely satisfactory. Under conditions not particularly favorable to the growth of fungi, several have met with considerable success. On the other hand, if the conditions were stimulating to fungous growth, the same substances often failed. Some treatments depend for their efficiency upon the neutralization of the acids in the wood and, at the same time, the establishment of alkaline conditions. To this group belong sodium carbonate, sodium bicarbonate, sodium hydroxid, lime, and borax. Others are intended to poison the food of the fungi, and comprise such compounds and mixtures as mercuric chlorid, copper sulphate, sodium fluorid, creosote, and many other substances.

Toxicity tests (Humphrey and Fleming, *24*)[20] conducted at the Madison laboratory upon a few molds commonly occurring upon infected timber, as well as upon several wood-destroying fungi, have clearly demonstrated that when the entire culture medium is permeated with these and many other preservatives, often in very small amounts, the growth of the fungus can be readily inhibited. Hence, if wood be thoroughly impregnated with a solution of one of these common preservatives it will be protected from decay as well as from sap-stain and mold.

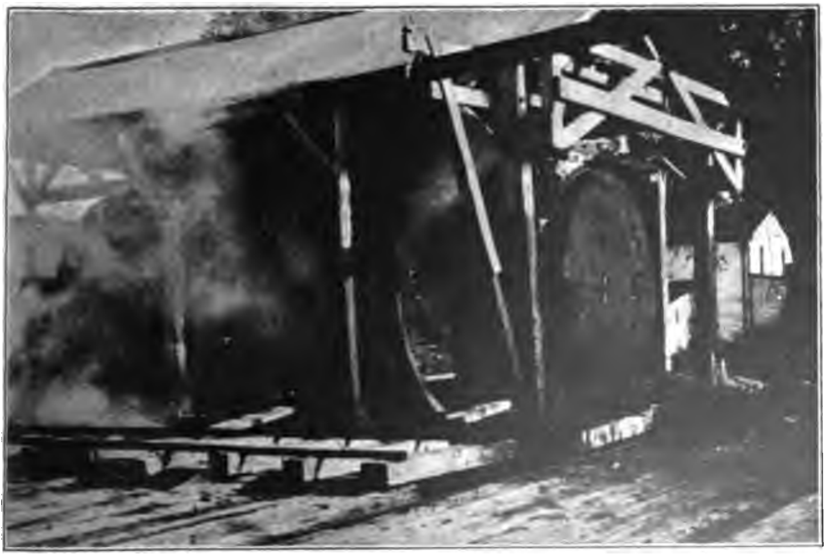

FIG. 14.—Preparator used for the commercial steaming of red-gum lumber at one of the mills in Arkansas.

This is quite possible in the case of thoroughly seasoned timber impregnated with preservatives by subjection to high pressure in closed retorts. The penetration of green timber by cold solutions of salts in an open tank or by the brush treatment, however, is extremely slight.[21] Tests made by the writer for the presence of copper in the interior of ¾ by ¾ by 1½ inch blocks sawed from the green sapwood of red oak and then dipped for 10 seconds in solutions of copper nitrate and copper sulphate at ordinary temperature showed that these solutions had penetrated the ends of the blocks for a distance less than 5 millimeters (one-fifth of an inch) and scarcely a measurable amount in the case of the tangential or radial surfaces. It is evident, then, that whatever value there is in the use of cold dipping solutions lies entirely in the superficial coating of the preservative left upon the wood. Provided this is not brushed off or washed off by rain, it may inhibit or prevent the germination of fungous spores which happen to fall upon such surfaces. Hot solutions, in that they tend to prevent the collection of bubbles of air upon the surface of the wood, probably give a more uniform distribution of the preservative over the dipped material. As far as penetration is concerned, however, it is doubtful whether the hot solutions, as ordinarily employed, possess any very great advantages. A slightly increased penetration may be secured by first subjecting the stock to a thorough steaming or by heating it for some time in a hot solution of the preservatives, as in the open-tank process. The air within the cavities of the wood is thereby expanded, and some escapes. Provided the steamed or hot wood is at once transferred to a cold solution of the preservative and there allowed to remain till

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[20] Information also obtained from unpublished reports of toxicity experiments performed by Miss C. Audrey Richards at the Laboratory of Forest Pathology, Madison, Wis.

[21] For a description of the pressure, open-tank, and brush treatments, the reader is referred to Forest Service Bulletin No. 78 (*45*) and to Farmers' Bulletin 744 (*25*), U. S. Department of Agriculture.

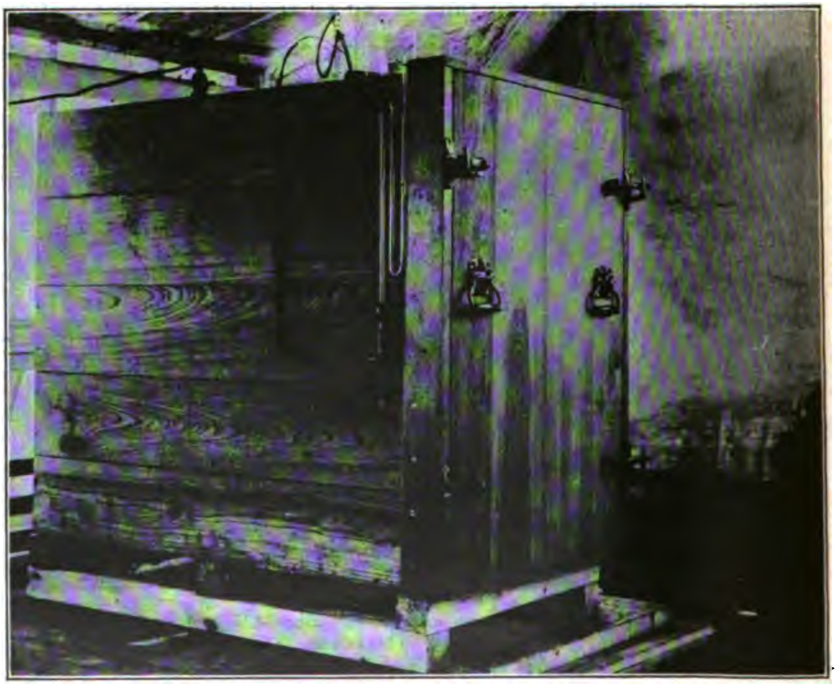

FIG. 15.—Steam box of cypress used in the experimental steaming of red-oak and white-oak blocks at the Madison laboratory.

cool, an amount, approximately equal to the original volume of the escaped air, will be forced into the wood. This is a slow process, however, and therefore somewhat expensive.

The rate of evaporation of the liquid, in the case of hot solutions, is much greater than in cold solutions; hence, it becomes necessary to take frequent hydrometer readings of the bath and to make the proper adjustments in the relative proportions of the solvent and dissolved substances in order to maintain a uniform concentration.

Dipping may be of some value when applied to stock free from fungi. In those cases where the fungi are already in the timber, however, it is doubtful whether very much good can result from chemical dips unless the material be subjected first to a relatively high temperature and for a length of time sufficient to destroy these organisms.

The salts used in the chemical treatment of lumber are likely to vary considerably in strength and purity. It is probable that the lack of uniformity in the results obtained by different investigators when employing nominally the same compounds may be traced partly to this cause. A few of the preservatives commonly used are described here.

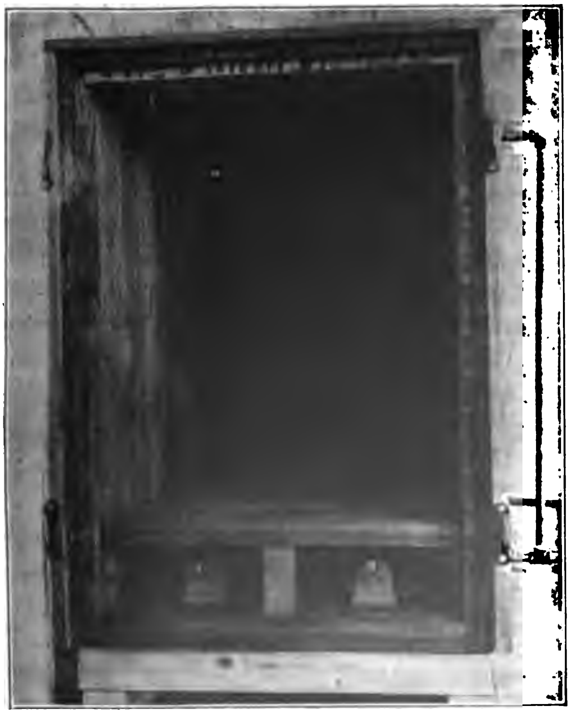

FIG. 16.—Details of the interior of the steam box used in the experimental steaming of red-oak and white-oak blocks at the Madison laboratory.

SODIUM CARBONATE AND SODIUM BICARBONATE.

The substances which have been most frequently employed to prevent sap-stain in lumber are sodium carbonate (commonly in the form of soda ash) and sodium bicarbonate (baking soda). Solutions of these salts are applied either hot or cold by dipping in an open tank. On southern yellow pine, when used in concentrations of 4 to 5 per cent sodium carbonate and 5 to 6 per cent sodium bicarbonate, these substances have given more or less satisfactory results (Weiss and Barnum, *57*). In wet weather, however, it has been found necessary practically to double the strength of the solutions. Moreover, both sodium carbonate and sodium bicarbonate cause a yellow to brown discoloration of the wood. Lumber treated with these preservatives must be open piled or it may mold and stain badly during warm, humid weather.

A good grade of sodium carbonate in the form of soda ash should contain 58½ per cent alkali, while the amount present in sodium bicarbonate (baking soda) is about 37 per cent. Solutions of the latter are more or less decomposed at temperatures above 158° F., giving off carbon dioxid. In a series of laboratory experiments followed by practical field tests on southern yellow pine and red gum, Rumbold (*37*) found that the blue-stain fungus is sensitive to alkalis but not to acids, that an 8 per cent solution of sodium carbonate is as effective as an 11 per cent solution of sodium bicarbonate, and that the amount necessary to prevent growth varies with the substratum. Freshly cut sapwood of southern yellow pine or red gum required 8 per cent sodium carbonate and 10 per cent sodium bicarbonate solutions under conditions which were especially favorable for the growth of the blue-stain fungus. In dry weather a weak solution of the alkali (a 5 per cent solution of sodium carbonate and a 4 per cent solution of the bicarbonate) kept the yellow pine boards free from stain. It was also observed that the spores of the blue-stain fungus are more resistant than the mycelium. These experiments seem to show that sodium carbonate and sodium bicarbonate possess some value as a preventive against sap-stain but that the success attending the treatment is largely dependent upon weather conditions.

SODIUM FLUORID, SODIUM BIFLUORID, AMMONIUM FLUORID.

Sodium fluorid, which has proved to be very toxic to wood-destroying fungi (Teesdale, *49*), has also been tested to determine its toxic properties in connection with the blue-stain fungus. Representatives[22] of the Forest Products Laboratory, working independently and in cooperation with certain lumber mills located in Mississippi and Louisiana, found that both sodium fluorid and sodium bifluorid were effective against sap-stain. The fluorids have an advantage over sodium carbonate and sodium bicarbonate in that they do not discolor the timber. One of these investigators, in a comparative series of experiments with a number of preservatives, including 2½ per cent sodium fluorid, 2½ per cent sodium bifluorid, and 2½ per cent ammonium fluorid, found that in the concentrations mentioned these salts were fairly effective against sap-stain. The ammonium fluorid, in addition, seemed to be of some value in controlling mold. However, both of these series of experiments were performed during hot and dry weather—conditions unfavorable to fungous growth; hence, it is impossible to draw satisfactory conclusions from the results.

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[22] Unpublished reports by Pettigrew and Knowlton in the files of the Forest Products Laboratory, Madison, Wis.

While the fluorids may be effective in controlling decay and, to a certain extent, stain-producing organisms, they can not be depended upon to prevent molding.

MERCURIC CHLORID.

Probably the best antiseptic to prevent sap-stain and mold in green wood stock is mercuric chlorid. When used on coniferous woods and on many of the hardwoods in concentrations of 0.1 per cent to 1 per cent, it has been found to be exceedingly efficient. The addition of 0.1 to 1 per cent hydrochloric acid is said to increase its stability. Mercuric chlorid, however, is extremely poisonous when taken internally. Many individuals show a marked susceptibility to the poison even when applied externally. Moreover, the solutions of mercuric chlorid are corrosive to iron, zinc, and many other metals commonly employed in dipping vats. For these reasons it can not be recommended for general use.

SOME RESULTS OBTAINED FROM THE USE OF ANTISEPTICS BY VARIOUS INVESTIGATORS.

It is probable that the efficiency of a given antiseptic varies considerably when applied to woods of different species and at various stages of air seasoning. As stated before, the results are likewise dependent upon climatic conditions. On open-piled boards of shortleaf pine in Missouri, Von Schrenk, Bessey, and Spaulding found that 5 per cent sodium bicarbonate or one-twentieth per cent mercuric chlorid gave good results (Hedgcock, *20*). On open-piled white pine in Wisconsin, the first two investigators found that the solutions giving the best results were 5 per cent borax and 2.5 per cent sodium bicarbonate, while on boards of Norway pine in open piles 5 per cent borax, one-twentieth of 1 per cent mercuric chlorid, and 2.5 per cent sodium bicarbonate were most effective (Hedgcock, *20*). As the result of experiments on longleaf pine boards in open piles at Bogalusa, La., Weiss and Barnum (*56*, *57*) concluded that the most effective antiseptics for the control of sap-stain, in that wood at least, are mercuric chlorid in concentrations of 0.1 to 1 per cent and sodium bicarbonate in strengths varying from 5 to 10 per cent. In these experiments 5 per cent borax gave poor results.

Hedgcock (*20*), in connection with certain experiments at Baltimore, Md., on the prevention of mold and stain in veneer baskets made from poplar, sycamore, beech, gum, and maple, found that the most effective solutions were 10 per cent sodium carbonate, 6.5 and 10 per cent sodium bicarbonate, 2.5 per cent sodium bicarbonate plus

0.66 per cent borax and boric acid, 0.20 per cent sulphur plus 0.20 per cent lime, 0.10 per cent mercuric chlorid plus 0.20 per cent hydrochloric acid, 10 per cent potassium (alum), and 0.33 per cent phenol salicylate. He concludes that of these substances, 5 to 10 per cent sodium bicarbonate is the safest and best to use.

In nearly all the cases cited the antiseptics proved to be of some value in preventing the growths of the sap-stain fungus. Molds, however, are extremely resistant to chemical treatment and consequently are difficult to control. To quote from Lafar (*28*): "Whether the waterproof character of some cell membranes, e. g., the conidia of Penicillium and Aspergillus, should be attributed to the deposition of excreted fatty or waxy substances must be left undetermined. Biologically this phenomenon is important, since it prevents the penetration of toxic substances from the aqueous medium and thereby also opposes the attempts of the mycologist to kill such fungi by means of aqueous toxic solutions." Since, as has been stated repeatedly, molds develop largely on the surface of the timber and are sufficiently removed during the several finishing processes to which the timber is sooner or later subjected, their presence in most cases should occasion but little concern in connection with vehicle stock.

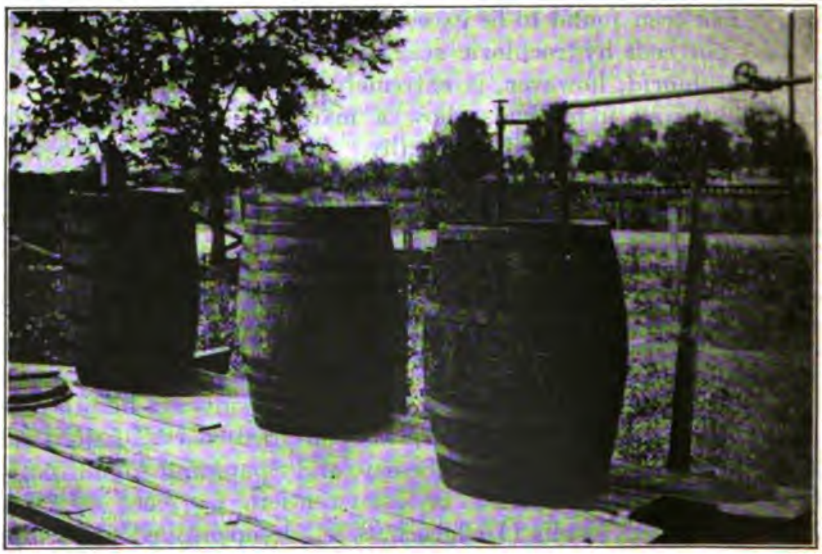

FIG. 17.—Barrels and steam-coil connections as used in the experimental dipping of red-oak spokes at one of the large spoke mills in the South.

EXPERIMENTAL DIPPING OF RED-OAK SPOKES.

DIPPING.

In July, 1918, several series of experiments were performed by the writer in cooperation with one of the large spoke mills of the

South. It was desired to test in a more practical way some of the antiseptics that had been used on a small scale during preliminary experiments at the Madison laboratory. In these experiments first-grade escort spokes 2¼ by 2¼ by 27 inches long of red oak were used. They were selected mainly for two reasons: First, red oak in a green condition was the wood, of all those used at this particular mill, which seemed to be the most liable to mold and sap-stain; second, the escort spoke was convenient to handle in connection with the dipping apparatus employed.

All spokes were taken directly from the warehouse after turning and grading. It was noted that 80 to 90 per cent of them contained sapwood varying in amount from 5 to 100 per cent.

In lieu of dipping tanks it was decided to use whisky barrels of 50-gallon capacity. Three of these were placed on a platform in the mill yard beside the tracks upon which the trucks were operated. One barrel was equipped with a steam coil of bent ½-inch iron pipe provided with shut-off valves (fig. 17). This coil, when connected with the main steam boiler, supplied the necessary heat for maintaining the temperature of the dipping solutions. A piece of corrugated, galvanized-iron plate, approximately 2 by 6 feet, when supported in a slanting position with the lower end resting upon the top of the barrel, served as a drain board. Iron tongs similar to those used by blacksmiths, hydrometers, thermometers, and a gallon measure completed the list of essential apparatus.

The following antiseptics were applied in the form of solutions or in a dry state:

(*a*) Barrett's grade 1 liquid creosote, 10 per cent by volume.
Perfection kerosene oil, 90 per cent by volume.
Temperature, 80° to 90° F.
(*b*) Barrett's grade 1 liquid creosote, 10 per cent by volume.
Perfection kerosene oil, 90 per cent by volume.
Temperature, 150° to 155° F.
(*c*) Powdered borax, 5 per cent by weight.
Water, 95 per cent by weight.
Temperature, 80° to 90° F.
(*d*) Mercuric chlorid (C. P.), 1 per cent by weight.
Hydrochloric acid (commercial), 1 per cent by weight.
Water, 98 per cent by weight.
Temperature, 80° to 90° F.
(*e*) Dry salt (finely grained).
(*f*) Dry quicklime (finely powdered).

The spokes were conveyed to the dipping barrels on trucks. There they were grasped by means of the iron tongs, immersed from 5 to 10 seconds in the bath, and then placed on the corrugated-iron drain board (fig. 18). When practically all of the excess liquid had drained off they were again grasped with the tongs, loaded upon another truck, and wheeled to the north end of one of the open sheds in the yard. There they were unloaded, close piled, and allowed to remain until ready for shipment.

During the dipping operation it was observed that in some cases as many as 10 to 15 per cent of the untreated spokes in a given truck load showed the presence of sap-stain. In one lot the number showing sap-stain and mold was estimated at 50 per cent. Other lots were practically free from fungi. During the experimental work the weather was for the most part hot and dry. Following one or two light showers the amount of mold on untreated material showed a marked gain.

The methods of dipping were similar for all baths except in the case of the hot creosote. Here, the steam coil was employed and a temperature of 150° to 155° F. maintained. One barrel served for both cold and hot creosote. The borax was dissolved by aid of the steam coil in the second barrel. A third barrel was necessary for the mercuric-chlorid dip. Thermometer and hydrometer readings were taken at frequent intervals, and whenever necessary corrections were made to maintain a constant temperature and concentration in the bath.

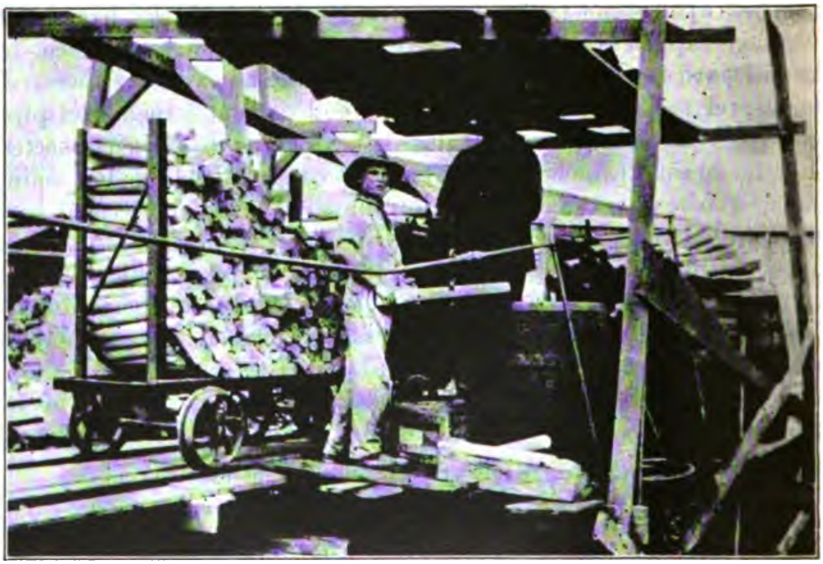

FIG. 18.—The experimental dipping of red-oak spokes green from the lathe.

Incidentally, it was noticed that ambrosia beetles were very quickly killed by the creosote dip, a point of importance to consider in controlling insect pests which at times, especially during warm and damp weather, are said to cause considerable losses in piled lumber.[23] (Weiss, *56*, p. 18–20.)

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[23] A certain species of beetle, *Dendroctonus ponderosae* Hopk., has been mentioned by Von Schrenk (*41*) as being partly responsible for the dissemination of the spores of the blue-stain fungus.

Both cold and hot solutions of creosote may cause considerable irritation, and in some cases blistering, when brought in contact with the skin. By proper use of the tongs, however, this trouble was avoided. Rubber gloves were worn during the dipping of spokes in the solutions of mercuric chlorid, since that salt, as already stated, is a deadly poison when taken internally and is sometimes absorbed through the skin when solutions are handled continuously.

Many metals, such as iron and zinc, possess the common property of precipitating metallic mercury from the solutions of its salts. For this reason the iron tongs and other metallic objects could not be used in connection with the mercuric-chlorid dip.

The spokes that were treated with salt or lime were placed, a few at a time, in wooden boxes containing the respective substances in a finely powdered state and were rolled to distribute the chemicals over them as evenly as possible. The excess was shaken off. They were then close piled in one section of the warehouse. After 24 hours the lime coating showed a marked tendency to absorb moisture and cake. Moreover, it turned the wood dark. For this reason the liming was discontinued after 300 spokes had been treated. The salted spokes soon became exceedingly moist, due to the hygroscopic nature of the salt. The antiseptics used and the number of spokes treated in the different lots follow:

(*a*) 10 per cent creosote in kerosene, cold	5,100
(*b*) 10 per cent creosote in kerosene, hot	5,100
(*c*) 5 per cent borax in water	1,013
(*d*) 1 per cent mercuric chlorid plus 1 per cent hydrochloric acid	1,000
(*e*) Dry salt	1,032
(*f*) Dry quicklime	300

The first lot went forward in a box car loaded to capacity with 5,000 cold-creosoted spokes, 5,000 that had been hot creosoted, 800 spokes that had been dipped in mercuric chlorid, and 350 that were untreated. It was originally intended to ship the other lots at the same time. The car, however, was found to be too small, so the borax-treated, salted, and limed spokes went forward at a later date.

Many of the cold-creosoted spokes that had lain in the shed for two to three weeks awaiting shipment were slightly molded. It was noticed that those with the mold were taken from that part of the pile that had suffered most from poor ventilation, namely, near the bottom and in the rear. The spokes in the other lots at that time seemed to be free from mold or sap-stain.

METHOD OF LOADING CAR NO. 1.

The spokes were stacked in transverse ricks, beginning at the end of the car and working toward the doorway. Each rick was built up in the following manner. A row consisting of five pairs of spokes all parallel to the length of the car was laid across the floor. An interval of perhaps 1 or 2 inches separated the members of a pair, and the distance between successive pairs was made a little less than the length of a spoke. Upon either end of these was laid a single transverse row of spokes. A third layer similar to the first and a fourth similar to the second were then laid down. With two more alternate layers a comparatively open base six layers in height and providing for partial aeration of the ricks was constructed. Upon this base the remaining spokes of the rick were close piled in successive layers, two or three spokes in depth. Each alternate horizontal layer was placed at a slight angle to those directly above and below, but all had a general direction lengthwise of the car. Each rick when built to within 2 feet or so of the roof contained on an average 833 spokes. As soon as one end of the car had been filled ricks were placed in the opposite end. In the doorway three longitudinal ricks were constructed and any space remaining was filled in with loose spokes. In this particular case one end of the car was stacked with the hot-creosoted spokes, the opposite end and 1⅓ ricks in the doorway being stacked with the cold-creosoted spokes. Parts of two ricks in or near the doorway comprised spokes treated with mercuric chlorid, and the remainder consisted of untreated spokes thrown in loosely between the longitudinal ricks and the doorway. Both doorways were boarded up with 6-inch boards spaced 1½ inches apart, and both doors were left open for about 1 foot. This car left the yard on July 24, consigned to one of the large vehicle factories of the North and reached its destination on August 14. On August 15 and 16 it was unloaded and inspected by C. J. Humphrey and the writer. During the time that the car was in transit the weather was in general hot and dry, although local showers may have been encountered.

CONDITION OF SPOKES IN CAR NO. 1 UPON ARRIVAL AT DESTINATION.

The inspection at the time of arrival was very thorough, each spoke being handled separately and a record kept of the number showing mold in any degree. Observations were also made, in a general way, of the extent of sap-stain and incipient rot. No attempt was made to discriminate between heavy and light infections, as these largely depended, with a given preservative, on the position of the spokes in the ricks or in the car with respect to the amount of ventilation received. In general, the top layers to a depth of 15 to 18 inches showed very little mold; likewise, the loosely arranged bases were quite free or comparatively so. The molds consisted for the most part of fluffy white to tawny mycelium, together with a comparatively small amount of green Penicillium. In the case of the cold-creosoted spokes, there seemed to be an increase over the amount which was observed on the same spokes at the time of loading. For convenience in presentation, the data relative to location in the car and condition are given in Table I.

TABLE I.—*Condition of the red-oak spokes in car No. 1 upon arrival at its destination.*

Location in car.[a]	Antiseptic.	Condition.	Percentage molded (based on 833 spokes per rick).
Forward end of the car:			
Loose in the doorway.	Untreated	Free from mold or sap-stain; a few badly checked.	
Stacked in the doorway and first rick.	Mercuric chlorid and hydrochloric acid.	None with mold or sap-stain; not so many checked as in the untreated lot.	
First rick	Hot creosote at 150° to 155° F.	None with mold; no sap-stain	
Second rick	do	68 with mold; no sap-stain	8.2
Third rick	do	431 with mold; no sap-stain	51.7
Fourth rick	do	277 with mold; no sap-stain	33.2
Fifth rick	do	218 with mold; no sap-stain	26.2
Sixth rick (end of the car).	do	222 with mold; no sap-stain	26.7
Opposite end of the car:			
Stacked in the doorway and first rick.	Cold creosote at 80° to 90° F.	69 with mold; no sap-stain	8.3
Second rick	do	492 with mold; no sap-stain	59.1
Third rick	do	348 with mold; no sap-stain	41.8
Fourth rick	do	207 with mold; no sap-stain	24.8
Fifth rick (end of the car).	do	142 with mold; no sap-stain	17.0

[a] Ricks are in each case numbered from the first transverse rick on either side of the area between the doors and extending back to the ends of the car.

It will be seen from Table I that the spokes that were placed in the doorway where better ventilation could be had did not mold or sap-stain. Those that were the most exposed, however, were inclined to suffer from checking. The largest proportion of molding took place in the second or third ricks, but in no case was this accompanied by sap-stain, and in no instance was it severe enough to necessitate culling. The considerable reduction in the fourth and fifth ricks, which was most marked in the rear end of the car, is difficult to explain. In the forward end, the motion of the train caused the last rick to slide away from the end of the car, and thus somewhat improved the ventilation. It is possible, then, that in the rear end the tendency of the mass of spokes to surge backward and forward whenever the continuous passage of the car was interrupted, together with the fact that a hole existed in the bottom of the car due to the breaking of a floor plank, may have provided sufficient ventilation to account for the low percentage of mold in the fourth and fifth ricks.

It was noted that the stage in the development of the mold on the creosoted material was an early one, namely, a white, fluffy mycelium, which in most cases had not advanced to the spore-producing condition. This indicates a retarding effect due to the treatment. It is also evident that the creosote, though unable entirely to control the mold, seemed to prevent the development of sap-stain. From the evidence it would also appear that heating the creosote to 150° or 155° F. does not increase its effectiveness to any marked degree, the difference in the percentage of moldy spokes in the two treatments being less than 1 per cent.

METHOD OF LOADING CAR NO. 2.

The second car, containing 1,032 salted, 1,013 borax-treated, 300 lime-treated red-oak, and the remainder untreated, white-oak escort spokes, was loaded on August 3 and 5.

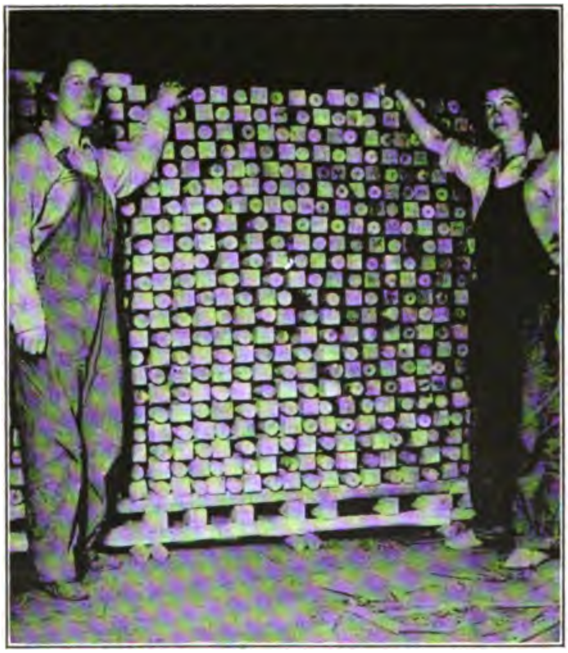

FIG. 19.—"Ricking," or stacking, treated escort spokes in a box car (car No. 2).

Those spokes that had been salted were exceedingly moist, owing to the hygroscopic property of the salt. On many of these species of Penicillium were found. The limed spokes were dark in color and in a few cases seemed to be developing sap-stain. The borax-treated spokes were apparently quite free from fungi.

The method used for stacking the spokes in the second car differed somewhat from that in the first. The base of each rick was constructed in the same manner, though of four instead of six layers. Upon this base the spokes were carefully stacked, using two 1½-inch by ¼-inch crossers of elm between successive layers (fig. 19). Each rick held on an average 840 spokes. The doorways were closed in the same manner as in car No. 1. This consignment left the yard on August 6 and arrived at the same factory located in the North on August 20, a period of two weeks in transit. During this time the weather was hot and comparatively dry.

CONDITION OF SPOKES IN CAR NO. 2 UPON ARRIVAL AT DESTINATION.

On August 21 the spokes were unloaded and inspected by C. J. Humphrey and the writer. Table II gives the location of the different lots and their condition upon arrival.

TABLE II.—*Condition of the spokes in car No. 2 upon arrival at its destination.*

Location in car.	Material.	Antiseptic.	Condition.	Percentage molded (based on 840 spokes per rick).
Ricks in the end of the car containing treated spokes:				
First rick......	White oak..	Untreated..................	147 moldy; a few sap-stained	17. 5
Second rick....	....do......	A few untreated layers at top	1 moldy....................	. 1
	Red oak....	Remaining layers borax, 5 per cent.	67 moldy; many sap-stained.	7. 9
Third rick.....	....do......	Top layers borax, 5 per cent.	7 moldy; many sap-stained..	. . 8
	....do......	Middle layers lime..........	4 moldy; some sap-stained... Spokes very dark in color.	. 4
	....do......	Bottom layer salt...........	34 moldy; some sap-stained..	4. 0
Fourth rick....	.....do......	Salt.........................	300 moldy; many with Penicillium in all parts of rick, badly damaged.	35. 7
Fifth rick......	White oak..	Untreated..................	330 moldy; much sap-stain..	39. 3
Sixth rick......	.....do......	.....do.....................	202 moldy; much sap-stain..	34. 8
Ricks in the doorway and in the opposite end of the car:				
In doorway....	.....do......	.....do.....................	No mold; no sap-stain.......	0
First rick......	.....do......	.....do.....................	87 moldy; many sap-stained.	10. 4
Second rick....	.....do......	.....do.....................	312 moldy: many sap-stained	37. 1
Third to sixth ricks.	.....do......	.....do.....................	Not examined...............	....

The proportion of infected spokes, based on the total number in the different lots in the end of the car containing these spokes, is:

Untreated	29 per cent moldy.
Salted	32. 3 per cent moldy.
Borax (treated)	7. 3 per cent moldy.
Lime (treated)	1. 3 per cent moldy.

These figures can by no means be used as a basis for an exact comparison of the values of the three preservatives. The location of the ricks in the car introduces another and very important factor. To note whether the hygroscopic property of the salt had a tendency to affect the humidity in the end of the car in which the salted spokes were stacked, thus influencing, perhaps, the amount of molding in adjacent lots, it was decided to observe the unloading of the spokes in the opposite end of the car After two ricks had been unloaded, however, it became evident that this was not the case, as conditions in that end were practically the same as in the first. From the data derived, at least from this lot, given in Table II, it would seem that salt when applied dry to green spokes is of little value in controlling either sap-stain or mold. Lime, though effective in preventing both mold and sap-stain, yet because of its darkening effect on the wood and its tendency to form calcium carbonate, which cases over the surface and is said to dull the knives used in subsequent processes of manufacture, is debarred from further consideration. Borax, however, with 7.3 per cent moldy spokes, seems to be somewhat effective against mold, but of less value in controlling sap-stain.

SUMMARY OF OBSERVATIONS.

Creosote dipping seemed to prevent sap-staining, but it had little effect upon mold. In no way did it detract from the sale value of the spokes.

The creosote bath at 80° to 90° F. was nearly as effective as at 150° to 155° F.

Mercuric chlorid, 1 per cent, seemed to be very effective in controlling both sap-stain and mold.

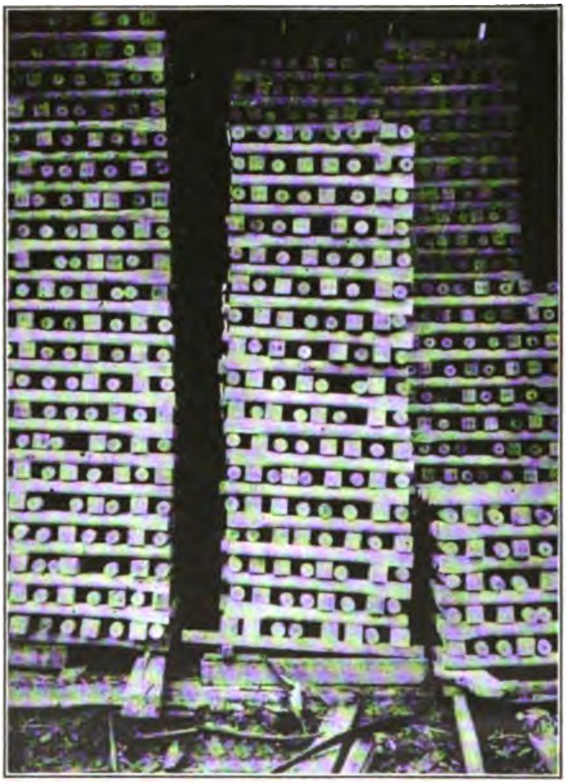

FIG. 20.—Green turned spokes cross piled in open or ventilated sheds. Green spokes are sometimes allowed to surface dry in this manner for one to two months preparatory to shipping in box cars.

Borax solution, 5 per cent, appeared to be somewhat effective in controlling mold, but of less value in regard to sap-stain.

The use of lime in the treatment of spokes was not satisfactory, on account of its darkening effect on the wood, the covering up of physical defects, and the probability of dulling the knives used in later processes of manufacture.

Salt sprinkled over the spokes was of no value in preventing either mold or sap-stain.

The ventilation of spokes in a box car is an important factor. Those spokes in the doorway, even if untreated, usually have but little tendency to mold or sap-stain.

Practically none of the spokes in either car were culled on account of defects due to fungi, although a few in the areaway between the doors were thrown out on account of slight checking.

No incipient decay was found in any of the material.

EXPERIMENTAL DIPPING OF RED-OAK BLOCKS AT THE LABORATORY OF FOREST PATHOLOGY, MADISON, WIS.

A comparison of the specific antiseptic values of the chemical substances employed in the spoke-dipping experiments can hardly be made, since these substances were not used in solutions of uniform strength. To determine, if possible, the comparative values of these and several other common antiseptics and preservatives in the control of mold and sap-stain fungi, several series of experiments were undertaken at the Madison laboratory. Where possible, solutions were made up to a calculated value of 1 per cent actual weight of anhydrous salt. The hygroscopic substances—sodium chlorid, calcium chlorid, and glycerin—were added in certain instances to determine whether or not they would increase the efficiency of the preservative by keeping the surface of the treated wood moist. A list of the substances used follows:

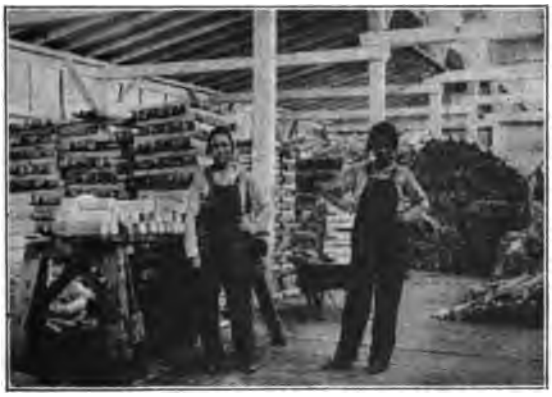

FIG. 21.—Storage of spokes in a warehouse. The truck spokes at the left have just been painted by girls with a resin-linseed oil mixture to prevent checking.

Alum (potassium).
Ammonium fluorid.
Bleaching powder.
Borax.
Copper sulphate.
Lead acetate.
Lead nitrate.
Magnesium silicofluorid.
Mercuric chlorid.
Mercuric chlorid and hydrochloric acid, 1 per cent.
Potassium chlorate.
Sodium fluorid.
Sodium bifluorid.
Zinc silicofluorid.
Creosote in kerosene.
Formalin.
Lysol.
Mykantin.
Orthonitrophenol.
Rongalite.

Red-oak blocks ¾ by ¾ by 1½ inches long, sawed from the sapwood of summer-cut logs, were used in each case. Ten blocks constituted a group. The individual blocks of a group were immersed for approximately 10 seconds in one of the respective solutions, drained, and then sprayed on all six sides with a water suspension of the spores taken from the same cultures as those used in the steaming experiments.[24] The sprayed blocks of each group were then close piled and placed in the tile chamber mentioned on page 29. An interval of at least 1½ inches was maintained between adjacent groups. In the tile chamber the blocks were subjected to a temperature averaging 80° F. and a relative humidity varying from 85 to 100 per cent. At the end of three to four weeks all blocks were carefully examined. The following observations were made at that time:

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[24] See page 29 for the list of fungi.

None of the preservatives was entirely effective in controlling mold when used in concentrations of 1 per cent.

Blocks dipped in sodium carbonate, sodium bicarbonate, sodium fluorid, sodium bifluorid, ammonium fluorid, magnesium silicofluorid, zinc silicofluorid, and bleaching powder became badly molded.

Potassium (alum), potassium chlorate, and copper sulphate seemed to stimulate all or certain species of the fungi used. The last seemed to incite the growth of *Aspergillus niger* in particular.

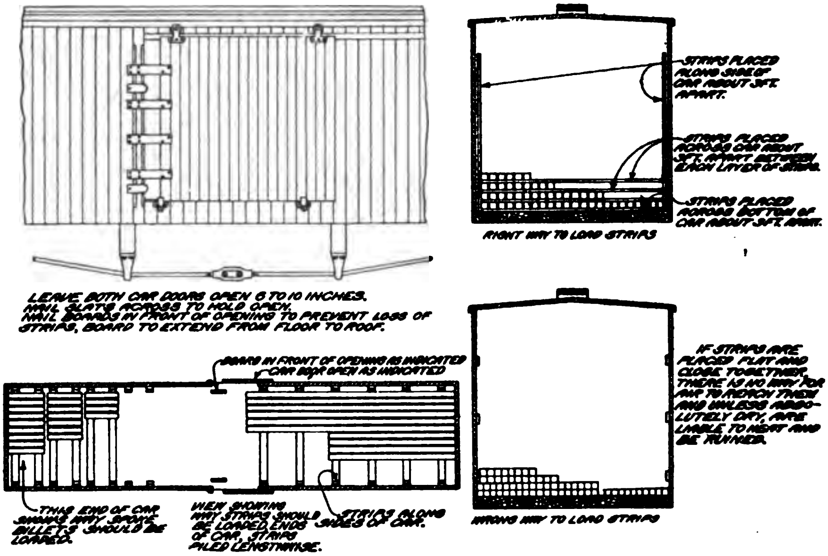
STRIPS PLACED ALONG SIDE OF CAR ABOUT 3 FT. APART.
STRIPS PLACED ACROSS CAR ABOUT 3 FT. APART BETWEEN EACH LAYER OF STRIPS.
STRIPS PLACED ACROSS BOTTOM OF CAR ABOUT 3 FT. APART.
RIGHT WAY TO LOAD STRIPS
LEAVE BOTH CAR DOORS OPEN 6 TO 10 INCHES.
NAIL SLATS ACROSS TO HOLD OPEN.
NAIL BOARDS IN FRONT OF OPENING TO PREVENT LOSS OF STRIPS, BOARD TO EXTEND FROM FLOOR TO ROOF.
BOARD IN FRONT OF OPENING AS INDICATED
CAR DOOR OPEN AS INDICATED
IF STRIPS ARE PLACED FLAT AND CLOSE TOGETHER, THERE IS NO WAY FOR AIR TO REACH THEM AND UNLESS ABSOLUTELY DRY, ARE LIABLE TO HEAT AND BE RUINED.
THIS END OF CAR SHOWS WAY SPOKE BILLETS SHOULD BE LOADED.
VIEW SHOWING WAY STRIPS SHOULD BE LOADED, ENDS OF CAR, STRIPS PILED LENGTHWISE.
STRIPS ALONG SIDES OF CAR.
WRONG WAY TO LOAD STRIPS

FIG. 22.—Diagram illustrating the method of loading used by one of the large wheel factories and recommended by the wood-stock committee in connection with vehicle stock.

Borax was effective in controlling the sap-stain fungus (*Ceratostomella* sp.). Though it did not entirely prevent the growth of mold, the amount of mold that did develop was very slight in comparison with that on the blocks treated with the other preservative solutions. Under these circumstances it compared favorably with 1 per cent mercuric chlorid.

The addition of the hygroscopic substances—sodium chlorid, calcium chlorid, and glycerin—to the solutions of the preservatives apparently did not increase their efficiency.

Of the organic compounds and mixtures tested here, creosote in kerosene gave the best results, while mykantin stood second. The latter, however, stained the wood yellow, a property which would prohibit its use for many purposes.

STORAGE OF GREEN DIMENSION, SAWED, OR TURNED STOCK AT THE MILL.

If it becomes necessary to store dimension or turned green stock without giving it the protection referred to, cross piling or stripping in properly ventilated sheds is absolutely essential (figs. 20 and 21). All strips should be narrow and at least three-fourths of an inch, but preferably 1 inch, in thickness and should be thoroughly seasoned or given some antiseptic treatment.

HANDLING GREEN DIMENSION, SAWED, OR TURNED STOCK IN TRANSIT.

If it becomes necessary to ship green dimension, sawed, or turned stock and planks during the late spring and summer months, attention must be paid to the cleanliness and ventilation of such material while in transit.[25] Cattle, vegetable, or ventilated box cars which have been previously cleaned are to be preferred for small stock. In ventilated box cars the end doors should be cleated open. If only box cars of the ordinary type are available, the material should be piled according to methods similar to the one shown in figure 22. In the case of spokes and sawed billets, a cross-piled foundation, four to six courses high, is recommended in addition to the directions given (figs. 23 and 24).

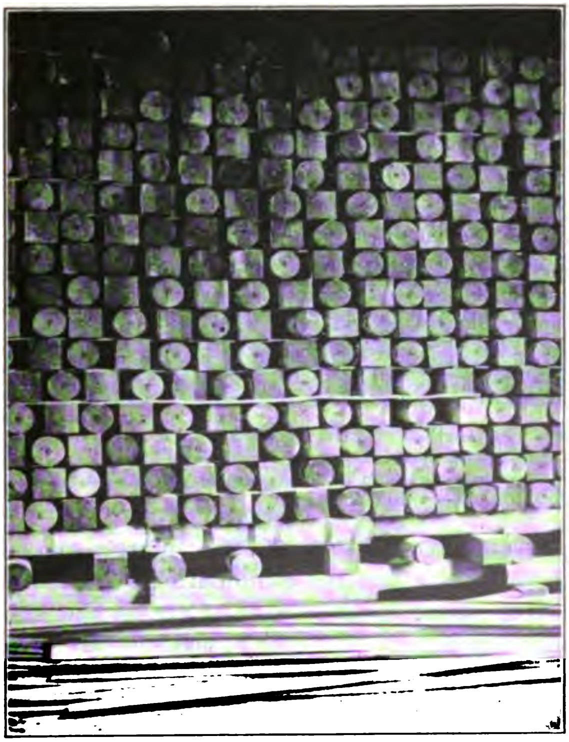

FIG. 23.—Artillery spokes "ricked" in a box car. Elm strips one-half inch by 1½ inches used between the courses.

When doors of box cars are loosely boarded up (fig. 25) or cleated open (figs. 9 and 22), it is recommended that they be spiked, that the bill of lading bear an indorsement to the effect that the doors were left open and cleated at the request of the shipper, and finally that

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[25] The directions given under "Provisions for the proper ventilation of stock in transit," page 23, apply here.

a. notice similar to that devised by one of the wheel companies and cited in Bulletin No. 30 of the wood-stock committee[26] be nailed to the car, reading as follows:

> TAKE NOTICE.—DO NOT CLOSE DOORS.—The lumber in this car is green and is carefully cross piled that there may be good circulation of air through the stock. The doors are left partly open and cleated by the shipper upon request of the consignee. If the doors are closed the stock will be liable to damage in transit.
>
> Should this car break down in transit, making it necessary to transfer the stock to another car, it should be stacked in the car in the same manner and doors left open in the same way.

The use of box cars is usually demanded by those in charge of bending mills where green rim stock is to be shipped. These cars expose the stock to less damage from checking. Unless attention is paid to stripping or some method of piling so as to insure ventilation. however, molding and sap-staining may result. One method used for the piling of rim strips in cars is shown in figure 26.

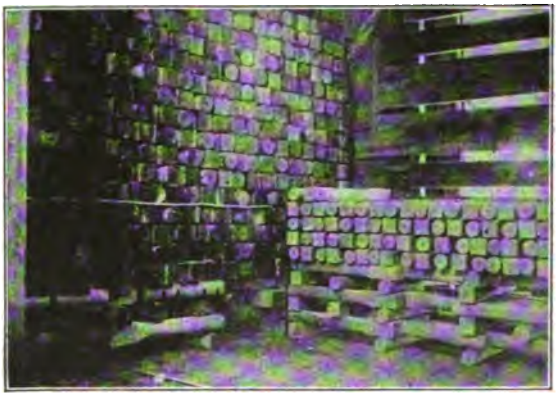

FIG. 24.—Artillery spokes "ricked" in a box car. A cross-piled base, strips, and open-boarded doorway are important details in the provision for proper ventilation of the stock while in transit.

SUMMARY.

It is evident that the prevention of sap-stain, mold, and incipient decay in green material, and in vehicle stock in particular, lies in a combination of remedial factors, the following being especially important: Care in the selection of raw stock in order to obtain, if possible, material free from fungous infections; expedition in the movement of raw stock from the felling of the logs to that time in the process of manufacture when the material becomes sufficiently dry to resist the attacks of fungi; provision at all times for ample ventilation of the stock that it may quickly become at least surface dried, thus making it difficult for the fungous spores to obtain from the exposed sapwood the moisture necessary for germination;

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[26] National Implement and Vehicle Association and other Vehicle and Vehicle Parts Manufacturers. Information Division of the Wagon and Vehicle Committee and the Wheel Manufacturers' War Service Committee. Wood Stock Committee. Sap-stain and mold in transit. Nat. Implement and Vehicle Assoc., etc., Bul. 30, 5 p. 1918. A. B. Thielens, chairman. Typewritten.

the kiln drying of the stock wherever possible and whenever the cost will permit; and in special cases steam treatment or the use of antiseptic dips, followed by proper piling to insure ample ventilation.

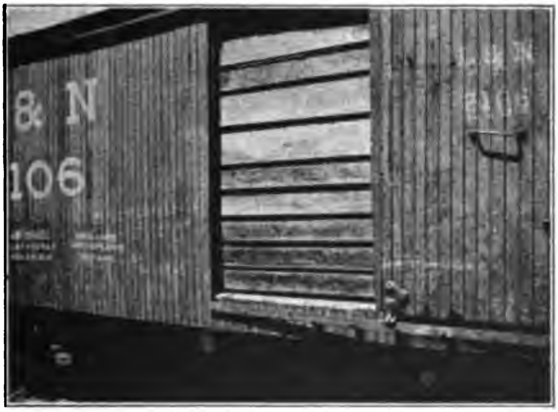

FIG. 25.—A box car loaded with spokes and ready for shipment. Spaces of 1½ inches are left between adjacent boards nailed across the doorways to allow for ventilation of the stock while in transit.

It must be continually borne in mind that none of these is by itself a sovereign remedy. Preservative dips or steam treatment were not in themselves, under the emergency manufacturing conditions incident to the war, by any means sufficient to control molding of green stock when close piled in storage warehouses or while in transit in box cars.

In connection with this investigation, it should also be borne in mind that we are dealing with three distinct groups of fungi, namely, the molds, staining organisms, and true wood-destroying organisms, the antiseptics being more efficient against the last two groups than the first. As far as is known, neither molds nor staining fungi cause any appreciable diminution in the strength of timber and hence are unimportant in vehicle manufacture from the standpoint of strength and probably durability. The staining fungi can be controlled to a certain extent by the intelligent use of antiseptics and possibly by steaming, and it seems reasonable, in the light of experience, to suppose that the development of wood-destroying fungi can also be prevented.

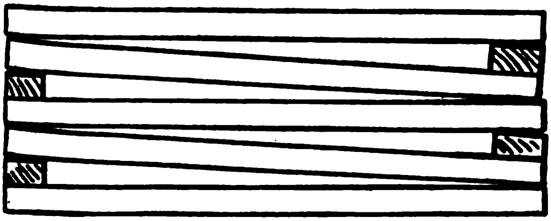

FIG. 26.—Zigzag method of piling rim strips in box cars.

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BULLETIN NO. 1

STUDIES IN WOOD DECAY I. LABORATORY TESTS ON THE RELATIVE DURABILITY OF SOME WESTERN CONIFEROUS WOODS WITH PARTICULAR REFERENCE TO THOSE GROWING IN IDAHO

By

HENRY SCHMITZ

and

A. S. DANIELS

1909

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STUDIES IN WOOD DECAY I[1] LABORATORY TESTS ON THE RELATIVE DURABILITY OF SOME WESTERN CONIFEROUS WOODS WITH PARTICULAR REFERENCE TO THOSE GROWING IN IDAHO.

By

HENRY SCHMITZ *and* A. S. DANIELS

Intelligent use is a fundamental concept of conservation. Thus the recent interest in conservation has given an unusual impetus to invesigations making possible a more rational utilization of the various species of wood.

Although information concerning the durability of the various American species of wood is rather meagre, Humphrey [2] conducted tests on both the heart and sap wood of a representative list of American woods. The results of these experiments were based upon single specimens of each sample of wood and may, therefore, not even be indicative of the relative durability of the various species tested and since many of the specimens became too wet for a fair test, comparisons between his results and those recorded here would be of very little value.

The painstaking work of Zeller [3, 4, 5] marks the beginning of a new era in investigations dealing with the durability of wood. Altho our results are not entirely in accordance with those found by him, it should be remembered that the species of pine investigated in the present study belong to different groups while those studied by Zeller all fall in the hard pine group.

The work of Schmitz [6] indicates that there may be a great difference in results obtained under laboratory pure-culture methods and those that would be obtained under natural conditions where there is the invariable presence of ordinary types of bacteria. It is therefore hoped that it will be possible to continue this work and extend it to natural conditions.

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[1] Several investigations are already in progress in the Forest Products Laboratory, University of Idaho, dealing with the decay of wood and it is proposed to give considerable attention to this important line of investigation during the next few years. These investigations will include studies on the durability of the various woods, the value of certain chemicals as preservatives, enzyme action in various wood destroying fungi, and various phases of the general phenomena of wood decay. In order to show the continuity or relationship between these several problems, it is proposed to group them under the general title of "Studies in Wood Decay," of which the present article is Number 1.—Henry Schmitz.

[2] Humphrey, C. J. Laboratory tests on the durability of American woods I. Flask tests on conifers. Mycologia 8: 80-92. pl.1. 1916.

[3] Zeller, S. M. Studies in the physiology of the fungi II. Lenzites saepiaria Fries, with special reference to enzyme activity. Ann. Mo. Bot. Gard. 3: 439-512. pl. 8-9. 1916.

[4] Ibid III. Physical properties of wood in relation to decay induced by Lenzites saepiaria Fries. *Ibid.* 4: 93-164. pl.9-13.f.1. Charts 1-11. 1917.

[5] Humidity in relation to moisture inbibition by wood and to spore germination on wood. *Ibid* 7: 51-74. 1920.

[6] Schmitz, H. Studies in the physiology of the fungi VI. The relation of bacteria to cellulose fermentation induced by fungi with special reference to the decay of wood. Ann. Mo. Bot. Gard. 6: 93-136. 1919.

PURPOSE

The purpose of the present study is to test the relative durability under laboratory conditions of the more important coniferous woods found in Idaho with the hope of extending the use of the so-called inferior species.

METHODS AND MATERIALS

The species of woods used in these tests were selected because of their apparent wide diversity of durability and since they represent the important western commercial woods. They are as follows: western white pine (*Pinus monticola* Dougl.), western yellow pine (*Pinus ponderosa* Lawson), Douglas fir (*Pseudotsuga taxifolia* (Poir.) Britt.), western larch (*Larix occidentalis* Nuttall.), western red cedar (*Thuja plicata* Don.), white fir (*Abies grandis* Lindley), and Engelmann spruce (*Picea engelmanni* Engelmann). The western larch, Engelmann spruce, western red cedar, western white pine and western yellow pine were obtained from a local lumber yard. The Douglas fir and white fir were donated by the Potlatch Lumber Company, Potlatch, Idaho.

The fungi used in the present study are: *Polyporus lucidus* (Lys.) Fries, *Lenzites saepiaria* Fries, *Fomes pinicola* Fries, *Merulius pinastri* (Fries) Burt, *Polystictus versicolor* (L.) Fries, *Pleurotus sapidus* Kalchbr, *Echinodontium tinctorium* Ellis and Everhart,*Trametes pini* Fries, *Trametes carnea* (Nees) Cooke, and *Lentinus lepideus* Fries. The cultures were obtained either by the tissue method as described by Duggar [7] or the spore method as developed by Zeller [8]. There is no question as to the purity of the cultures. The stock cultures of the fungi are maintained on both hardwood and pine sawdust and for these experiments, transfers were taken from the pine sawdust cultures.

One inch boards composed entirely of heart wood were obtained and were resawed into blocks measuring ¾x1x3 inches.

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[7] Duggar, B. M. The principles of mushroom growing and mushroom spawn making. U. S. Dept. Agri. Bur. Pl. Ind. Bul. *85*. 1-60 pl. 1-7. 1905.

[8] Zeller, S. M. *loc. cit.*

The blocks were dried to constant weight in an electric oven at 100°C. and weighed to the nearest 0.01 gram. Except in the case of Engelmann spruce, ten blocks of each species were placed in each of ten two-quart Mason jars having a layer of absorbent cotton on the bottom. The purpose of the cotton is merely to absorb any excess moisture and thus insure a more even water supply. In the case of Engelmann spruce, eight blocks were placed in each of ten two-quart jars also having the layer of absorbant cotton on the bottom. The blocks were placed on end in every case.

To each jar 250 cc. of distilled water were added. The amount of water to be added was roughly determined by adding varying amounts of trial flashs so that after sterilization the blocks and cotton were well moistened. In the case of the jars containing larch a small amount of free water remained when sterilization was completed. After a comparatively short time, however, this free water was taken up by the blocks. After the water had been added, the jars were carefully plugged with cotton plugs and sterilized. Sterilization was effected at fifteen pounds pressure for twenty minutes. It may be objected that by this method of sterilization certain volatile components of the resins which might be present in the wood would be driven off. Be that as it may, such very volatile components would soon disappear from the wood on exposure to the air and accordingly this would not be a deciding factor in the durability of any particular wood.

The inoculations were made as follows: transfers from sawdust cultures of the fungi were made to sterile hard agar plates. When practically the entire surface of the plate was grown over with mycelium, it was cut by means of a sterile scalpel into small squares with an area of approximately one square centimeter. With a very few exceptions, a single square was added to each of the culture jars. An effort was made to locate the inoculum in the center of the group of blocks. The fact is of course appreciated that by this method of inoculation the blocks in the center of the group may become infected first and may be well along the road to decay before the mycelium comes in contact with the blocks in the periphery of the group. When wood specimens are subjected to decay under laboratory conditions, there is usually a great diversity in the results for any given wood. This is true whether the individual specimens are in different culture jars or in the same culture jars. The reasons for this variation are not definitely known and it may merely be the law of "chance" that determines whether or not infection takes place. Whatver it be, "chance" or any other factor, that influences the possibility of infection it must, *a priori,* largely determine the resistance to decay of any specific wood. However, since the cultures were incubated for almost one year and since the average of ten blocks was taken in each case except in that of Engelmann spruce, where an average of eight was taken, it is felt that this fact offers no serious objection.

After inoculation the culture jars were incubated for a period of 10.5 months at room temperature. It was found necessary to water the blocks several times during this period. Whenever this was done, sterile distilled water was added and every effort was made to have the moisture conditions in all of the culture flasks as nearly the same as possible.

After the period of incubation, the blocks were again dried to constant weight in an electric oven at 100°C. and weighed. The difference in weight in the two weighings represents the amount of decay. The results for the ten blocks in each jar were averaged and the percent loss in weight calculated on the basis of the dry weight of the wood.

RESULTS

In Table I, the average loss in weight percent of ten blocks after ten and one half months' incubation at room temperature is given.

TABLE I.

Showing average loss in weight in per cent after ten and a half months' incubation when subjected to the action of the various fungi indicated.

Fungus	Pine, White	Pine, Yellow	Fir, Douglas	Larch	Cedar	Fir, White	Spruce	Ave. loss all woods in weigght
1. Polyporus lucidus	14.1	3.9	5.5	5.7	0.2	3.5	4.1	5.3
2. Lenzites saepiaria	50.5	30.0	11.8	5.4	0.3	10.6	9.8	16.9
3. Fomes pinicola	28.1	11.6	6.7	7.7	0.4	11.3	9.3	10.7
4. Merulius pinastri	3.7	3.8	3.1	*	0.3	2.3	1.2	2.4
5. Polystictus versicolor	2.3	3.1	1.5	4.5	0.5	1.3	2.3	2.2
6. Pleurotus sapidus	9.4	3.4	5.1	5.1	0.3	2.2	3.1	4.0
7. Echinodontium tinctorium	5.6	3.6	4.6	6.2	0.4	4.1	3.8	4.0
8. Trametes pini	3.8	2.2	3.8	7.5	0.2	1.4	2.3	3.0
9. Trametes carnea	10.2	17.4	12.2	8.4	0.3	2.0	3.9	7.8
10. Lentinus lepideus	33.0	39.2	15.8	7.3	0.4	1.2	10.6	15.3
11. Control	0.3	0.3	0.2	0.4	0.3	0.3	0.3	
Average loss in weight (all fungi)	16.1	11.8	7.0	6.4	0.3	4.0	5.0	7.2

* This flask broken by accident.

A study of the results tabulated in Table I brings out some very interesting points not only relative to the various woods but relative to the action of the various fungi.

Under the conditions described, the average loss in weight in the woods used due to the action of the fungi is 7.2%. Only white pine and western yellow pine lost more weight than this general average. Douglas fim represented approximately the average loss in weight and western larch, Engelmann spruce, white fir, and western red cedar are below the average, in the order named.

The maximum amount of decay is caused by the action of

Lenzites saepiaria on white pine and the following show less decay in the order named: *Lentinus lepideus* on western yellow pine, *Lentinus lepideus* on western white pine, *Lenzites saepiaria* on western yellow pine and *Fomes pinicola* on western white pine. It is significant that the five highest rates of decay are found on western white and western yellow pine. The fungi causing these losses in weight are not in any way peculiar to the two species of wood, but are found generally on both coniferous and the hard woods.

The results in the case of white fir are indeed interesting. Although this wood is usually considered as being very susceptible to decay, under the conditions of these experiments it is only surpassed by western red cedar in its resistance to decay. Even *Echinodontium tinctorium,* the fungus causing the very prevalent brown heart wood rot of white fir, did not cause even the average amount of decay. This may be explained in part by the fact that the fungus grows rather slowly. The slow rate of growth of *Echinolontium tinctorium* on hard agar and carrots has been previously reported by Schmitz [9].

As anticipated none of the fungi used made any apparent growth on western red cedar. It is evident from the table that the results obtained in the case of each fungus approximate the limit of error as found in the controls for that species. The cause or causes of the durability of this species will be the subject of further investigation in this laboratory.

The most desructive fungus as shown by the highest average rate of decay is *Lenzites saepiaria.* The physiology of this fungus has been carefully investigated by Zeller [10]. *Lentinus lepidus, Fomes pinicola,* and *Fomes carnea* follow in degree of destructiveness in order named.

Working with various species of pines, Zeller [11] has shown that "specific gravity or density materially influence resistance to decay of the heartwood, i. e., the more dense the wood, the more durable it is." However, this may be within a genus, it is evident that it does not necessarily hold between different genera since the specific gravity of larch is greater than that of Engelmann spruce, white fir or cedar.

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[9] Schmitz, H. Enzme action in *Echinodontium tinctorium.* Ellis and Everhart. Jour. Gen. Phys. 2: 613-616. 1919.

[10] Zeller, S. M. *loc. cit.*

[11] Zeller, S. M. *loc. cit.*

The work of Zeller[13] also indicates that in the case of the various species of pine investigated by him that "the width of the growth rings furnishes a further index of durability, the narrower rings showing more resistance to fungous attack than broad, open rings." The results recorded in the present paper indicate that this relation need not necessarily hold between different genera since the samples of larch used in the present work had an average of 32 rings per inch while white fir had an average of five rings per inch. Even within the genus Pinus, this relation did not hold since the western white pine used had an average of 26 rings per inch while the western yellow pine had an average of 12 rings per inch. It is evident that in this case a soft pine is compared with a hard pine while the pines studied by Zeller all belonged to the hard pine group.

As has been said, the average loss in weight induced by all the fungi on all the woods is 7.2 per cent. A study of Table I indicates that four fungi, namely: *Lenzites saepiaria Lentinus lepidus, Fomes pinicola* and *Fomes carnea* induced a rate of decay above this average.

While no direct study was made relative to the rate of growth of the various fungi used, even a cursory observation shows that these four fungi are among the more rapidly growing species. Although *Echinodontium tinctorium* and *Trametes pini* are among the more important forms causing heart wood rots in the Northwest the average rate of decay induced by them is low. This, as has been mentioned, may in part be explained by the fact that they are relatively slow growing forms. Even so, the relation between rate of growth and rate of decay need not necessarily hold, for example, *Polystictus versicolor* has a relatively rapid rate of growth but induced a low rate of decay. Detailed information concerning the relative rate of growth of the common and more important wood destroying forms would be of great practical and immediate importance in determining how soon after a fire or other disaster a tree would become badly decayed.

From a technical and practical point of view, it is evident that under certain conditions, as for example those of these experiments, white fir is not as susceptible to decay as generally thought. When the susceptibility to decay of any wood is considered, the fungus inducing that decay must also be considered.

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[13] Zeller, S. M. *loc. cit.*

For example, *Fomes pinicola* induced a higher rate of decay in white fir than in Douglas fir while *Fomes carnea* induced a much higher rate of decay in Douglas fir than in white fir.

If the average rates of decay are considered, the results indicate that with the exception of western red cedar, under the conditions of these experiments, white fir is the least susceptible to decay while western white pine is the most susceptible and Douglas fir represents approximately the average degree of durability.

It is clearly recognized that, however interesting the above results may be, before they can be generally accepted it will be necessary to carry out similar experiments under natural conditions. The various species of wood should be used under similar conditions and a careful study of the results made. The School of Forestry is at present carrying on these experiments.

CONCLUSIONS

It would seem that, from the results of the preliminary experiment above discussed, it would be safe to conclude that:

1. White fir and Englemann spruce may not be as susceptible to decay as generally thought.

2. When different genera are considered, the specific gravity of the wood is not necessarily an indication of its durability.

3. Within the same genus, the number of annual rings per inch is not necessarily an indication of the durability of the various species.

4. Certain fungi causing very prevalent and complete heart rots of standing timber may not induce a high rate of decay due to their slow growth.

5. The durability of any wood is not only a question of the inherent properties of the wood itself, but also depends upon the species of fungi prevalent in any particular locality in which the wood is used.

6. Under the conditions of these experiments, western red cedar is the least susceptible to decay, while western white pine is most susceptible and Douglas fir represents approximately the average of durability.

7. Experiments involving the use of the different species of wood under natural conditions are necessary before final conclusions can be drawn.

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STUDIES IN WOOD DECAY.

II. ENZYME ACTION IN POLYPORUS VOLVATUS PECK AND FOMES IGNIARIUS (L.) GILLET.

BY HENRY SCHMITZ.

(*From the Laboratory of Forest Products, School of Forestry, University of Idaho, Moscow.*)

(Received for publication, April 25, 1921.)

The present paper is the third of a series,[1,2] of papers dealing with the enzyme action in the wood-destroying fungi. It is the second of a series[3] of papers to be issued by this Laboratory dealing with the decay of wood in the broadest sense.

From the standpoint of parasitism, *Polyporus volvatus* is one of the most interesting of the wood-destroying fungi. Although no inoculation experiments have been made, numerous observations tend to confirm the opinion of the writer that *Polyporus volvatus* is truly parasitic. Throughout Washington, Oregon, and Idaho it is not at all unusual to find fruiting bodies of *Polyporus volvatus* appearing in great numbers over practically the entire surface of the trunk of Douglas fir, white fir, and western hemlock. This condition may be observed on trees still having a green, healthy foliage as well as on trees which to all appearances have been killed by the fungus.

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[1] Schmitz, H., and Zeller, S. M., Studies in the physiology of the fungi IX. Enzyme action in *Armillaria mellea* Vahl., *Daedalea confragosa* (Bolt.) Fr., and *Polyporus lucidus* (Leys.) Fr., *Ann. Missouri Bot. Garden*, 1919, vi, 193–200.

[2] Schmitz, H., Enzyme action in *Echinodontium tinctorium* Ellis and Everhardt, *J. Gen. Physiol.*, 1919–20, ii, 613.

[3] Schmitz, H., and Daniels, A. S., Studies in wood decay I. Laboratory tests on the relative durability of some western coniferous woods with particular reference to those growing in Idaho, School of Forestry, Univ. Idaho, Bull. 1, 1921, 1–12.

The fact that *Polyporus volvatus* may be parasitic seems to have been first suggested by Zeller[4] in an unpublished paper. Dr. Zeller writes in part, "The fact that there were still needles on the last year's growth and that the mycelium had spread from the base of the tree up the trunk for 45 to 50 feet indicates that the fungus is parasitic. The writer has no absolute proof of this statement."

In this region *Fomes igniarius* is the cause of a serious white heart rot in the common aspen (*Populus tremuloides*) and also causes a a similar heart rot in mountain birch (*Betula fontinalis*). Quite recently Weir[5] has reduced *Fomes igniarius* and *Fomes nigricans* Fr. to synonomy.

Thus, the two fungi considered here are not without considerable interest both from the general and economic point of view.

Methods.

The cultures of the fungi used in the present study were obtained from young sporophores by the tissue method. As before, the cultures were grown on sterile carrots and while still in an active growing condition, removed from the flasks, dried, and ground. All of the enzyme cultures were set up in duplicate and 0.25 gm. of fungous meal was invariably used. Otherwise, the methods followed are those previously described.

Esterases.

The esterase activity of *Polyporus volvatus* and *Fomes igniarius* was studied by the use of 1 per cent solutions of methyl acetate, ethyl acetate, ethyl butyrate, triacetin, and olive oil emulsion. After twenty-one days incubation, hydrogen ion concentration determinations were made of the various filtrates. Positive esterase activity was obtained in the case of both fungi when methyl acetate was used as the substrate. The action on all the other substrates was negative.

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[4] Zeller, S. M., Wood destroying fungi of Washington. Unpublished paper.

[5] Weir, J. R., Some observations on abortive sporophores of wood destroying fungi. *Phytopathology*, 1915, v, 48–50.

Carbohydrases.

The action of carbohydrases was determined on 1 per cent solutions of maltose, lactose, sucrose, raffinose, potato starch, inulin, white fir cellulose, and hemicellulose from date seed endosperms. After varying periods of incubation, the cultures were filtered and 5 cc. samples of the filtrates treated with 20 cc. of Fehling's solution. The results in the following table are the average of two titrations and are expressed as the number of cubic centimeters of 0.05 N potassium permanganate solution required to oxidize the dissolved copper.

TABLE I.

Carbohydrase Action of Polyporus volvatus and Fomes igniarius.

Incubation period.	Substrate.	*Polyporus volvatus.*			*Fomes igniarius.*	
		With fungous meal.	With fungous meal autoclaved.	Without fungous meal.	With fungous meal.	With fungous meal autoclaved.
		0.05 N $KMnO_4$				
days		*cc.*	*cc.*	*cc.*	*cc.*	*cc.*
14	Maltose	21.85	14.70	13.25	30.40	17.15
20	Lactose	26.65	21.40	18.30	29.60	22.00
3	Sucrose	4.35	3.65	0.75	13.10	6.00
4	Raffinose	8.80	3.55	0.10	11.50	4.35
4	Potato starch	19.00	2.75	0.10	8.10	3.55
10	Inulin	5.00	3.10	0.15	7.50	5.00
30	White fir cellulose	6.00	2.85	0.20	8.00	4.95
30	Hemicellulose	7.80	3.45	1.80	8.70	5.25

Glucosidase.

The presence of a glucosidase in the fungous meal of the two fungi here discussed was determined by the action of the fungous meal upon a 1 per cent solution of salicin. After a 5 day incubation period, the enzyme cultures were filtered and sugar determinations made of 5 cubic centimeter samples of the filtrates. The results, expressed in the number of cubic centimeters of 0.05 N potassium permanganate solution required to oxidize the dissolved copper are shown in Table II.

Tannase.

Under the action of tannase, digallic acid is probably converted into gallic acid in accordance with the general formula,

$$C_{14}H_{10}O_9 - H_2O = 2C_6H_2(OH)_3COOH$$

Whether or not this reaction took place was determined by titrating the filtrates against 0.05 N iodine after the digallic acid had been precipitated out by the addition of albumin and the albumin salted out with NaCl. As indicated in Table III, the results are negative.

TABLE II.

Glucosidase Action of Polyporus volvatus and Fomes igniarius.

	Polyporus volvatus.	*Fomes igniarius.*
	0.05 N $KMnO_4$	
	cc.	*cc.*
1 per cent salicin + fungous meal	11.10	15.15
1 “ “ “ + “ “ autoclaved	3.50	4.50
1 “ “ “	0.40	0.40

TABLE III.

Tannase Action of Polyporus vovatus and Fomes igniarius.

Enzyme Culture.	*Polyporus volvatus.*	*Fomes igniarius.*
	0.05 N iodine.	
	cc.	*cc.*
1 per cent digallic acid + fungous meal	4.7	3.9
1 “ “ “ “ + “ “ autoclaved	4.7	3.9
1 “ “ “ “	3.5	3.5

The absence of tannase in *Polyporus volvatus* is difficult to account for since the fungus inhabits the barks of trees having a high tannin content. Its absence may, however, be due to the fact that the culture medium upon which it had been grown contained little or no tannin. The influence of the culture medium on the production of tannase in fungi has been fully investigated by Knudson.[6]

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[6] Knudson, L., Tannic acid fermentation. I, *J. Biol. Chem.*, 1913, xiv, 159. Figs. 1 and 2; Tannic acid fermentation. II, 185.

Urease and Amidase.

To determine the presence or absence of enzymes which split amino-acids and urea into ammonia and hydroxy acids, the indicator method suggested by Schmitz and Zeller[1] was employed. The results are shown in Table IV.

TABLE IV.

Urease and Amidase Activity of Polyporus volvatus and Fomes igniarius.

	Enzyme culture.		Approximate change in hydrogen ion concentration.	
			Urea.	Acetamid.
			pH	*pH*
Polyporus volvatus	Substrate + fungous meal	1	5.6–6.0 3 min.	5.6–5.6 3 min.
		2	5.6–6.0 3 min.	5.6–5.6 3 min.
	Substrate + fungous meal autoclaved	3	5.6–6.0 3 min.	5.6–5.6 3 min.
		4	5.6–6.0 3 min.	5.6–5.6 3 min.
Fomes igniarius.	Substrate + fungous meal	1	5.6–7.8 45 sec.	5.6–5.6 3 min.
		2	5.6–7.8 45 sec.	5.6–5.6 3 min.
	Substrate + fungous meal autoclaved	3	5.6–6.0 3 min.	5.6–5.6 3 min.
		4	5.6–6.0 3 min.	5.6–5.6 3 min.
Control.	Substrate alone	1	5.6–6.0 3 min.	5.6–5.6 3 min.
		2	5.6–6.0 3 min.	5.6–5.6 3 min.

Positive results were obtained only in the case of *Fomes igniarius* when urea was used as a substrate.

Rennet.

When 0.25 gm. of fungous meal was added to 10 cc. of fresh milk, coagulation occured in 3 hours in the case of *Polyporus volvatus*, and in 4½ hours in the case of *Fomes igniarius*.

Catalase.

The presence of catalase was demonstrated by the action of the fungous meal upon a 3 per cent solution of hydrogen peroxide. When 0.25 gm. of the meal was added to 100 cc. of solution, 9.5 cc. of oxygen were liberated in the case of *Polyporus volvatus*, and 12 cc. in the case of *Fomes igniarius* in a period of 5 minutes.

Protease.

Tryptic and ereptic fermentation was studied by the use of albumin, peptone, casein, and fibrin in enzyme cultures having a neutral acid and alkaline reaction. The biuret test was employed in testing for the action of erepsin. The enzyme cultures were filtered, crystalline ammonium sulphate was added to the filtrate to precipitate the native proteins, and the solutions were again filtered through boneblack to remove the precipitate. In no case was a pink color produced when sodium hydroxide and dilute copper sulphate were added to the second filtrate.

A tryptophane test was also made of the filtrate by adding a few drops of glacial acetic acid and a few drops of strong bromine water. In no case was a pink color produced.

SUMMARY.

Circumstantial evidence is presented which indicates that *Polyporus volvatus* is parasitic.

Cultures of *Polyporus volvatus* and *Fomes igniarius* may be obtained from the young sporophores by the tissue method.

In *Polyporus volvatus* the presence of the following enzymes was demonstrated: esterase, maltase, lactase, sucrase, raffinase, diastase, inulase, cellulase, hemicellulase, glucosidase, rennet, and catalase.

In *Fomes igniarius* the presence of the following enzymes was demonstrated: esterase, maltase, lactase, sucrase, raffinase, diastase, inulase, cellulase, hemicellulase, glucosidase, urease, rennet, and catalase.

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ENZYME ACTION IN ECHINODONTIUM TINCTORIUM ELLIS AND EVERHART.

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In a recent paper[1] it was pointed out that information concerning the physiology of the wood-destroying fungi is comparatively meager. The intention to investigate the enzyme action in some of these forms was also expressed there. The present paper is the second of a series dealing with this phase of metabolism of the wood-destroying fungi.

Echinodontium tinctorium is perhaps one of the most destructive heart rot diseases in the West. White, Alpine, grand, noble, and Douglas fir, Engelmann's spruce, and western and mountain hemlock have been reported as having been affected. Perhaps by far the greatest damage occurs on white fir and western hemlock. The economic importance of this fungus has been sufficiently discussed by Weir and Hubert[2] and also by Meinecke[3] so that no further discussion of its economic importance or distribution is necessary.

The culture of the fungus used in this study was obtained from a young sporophore by the tissue method. The sporophore was carefully washed with sterile distilled water, dried by means of sterile tissue towelling, and cut open. Small portions of tissue were taken from the interior of the fruiting body and transferred to potato agar slants. After the fungus had made considerable growth, transfers were made from the agar slants to sliced sterile carrots in large Erlenmeyer flasks, and the cultures incubated for 3 months at a temperature of 32°C. The fungus makes comparatively slow growth both on hard potato agar and on the carrots. While still in an actively growing condition the fungous mats were removed from the flasks, and, when thoroughly dry, were finely ground.

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[1] Schmitz, H., and Zeller, S. M., Studies in the physiology of the fungi IX. Enzyme action in *Armillaria mellea* Vahl., *Daedalea confragosa* (Bolt.) Fr., and *Polyporus lucidus* (Leys.) Fr., *Ann. Missouri Bot. Garden*, 1919, vi, 193–200.

[2] Weir, J. R., and Hubert, E. E., Forest disease surveys, *U. S. Dept. Agric., Bull. 658*, 1918, 1–23.

[3] Meinecke, E. P., Forest trees common in California and Nevada, *U. S. Dept. Agric., Forest Service*, 1914, 1–67.

All the methods followed in the present study are similar to those in the former paper.[1] This was done in order to make the results as comparable as possible.

Esterases.

The esterase activity of ***Echinodontium tinctorium*** was determined by the action of the ground fungous meal on methyl acetate, ethyl acetate, ethyl butyrate, triacetin, and olive oil emulsion. After 21 days incubation hydrogen ion concentration determinations of the various enzyme cultures and controls were made and compared. Marked esterase activity occurred when methyl acetate and ethyl acetate were used as substrates, a trace of activity when methyl butyrate was employed, but no apparent activity when triacetin and olive oil emulsion were used as substrates.

Carbohydrases.

Carbohydrase activity is, no doubt, the most important and most interesting phase in the study of the physiology of the wood-destroying fungi with reference to enzyme action. The action of the fungous meal was determined on 1 per cent solutions of maltose, lactose, sucrose, raffinose, potato starch, inulin, white fir, filter paper cellulose, and hemicellulose. After varying periods of incubation the enzyme cultures were filtered and 5 cc. samples of the filtrate treated with 20 cc. of Fehling's solution. In Table I the average results of two titrations are given as the number of cc. of 0.05 N potassium permanganate required to oxidize the dissolved copper oxide. The results indicate evident action on all the substrates.

TABLE I.

The Carbohydrase Action of Echinodontium tinctorium.

Incubation period.	Substrate.	With fungous meal.	With fungous meal autoclaved.	Without fungous meal.
		0.05 N $KMnO_4$.		
		cc.	*cc.*	*cc.*
14 days	Maltose	31.3	19.1	15.1
20 "	Lactose	27.5	24.7	21.2
3 hrs.	Sucrose	8.2	5.3	0.2
3 days	Raffinose	6.1	4.0	0.3
6 hrs.	Potato starch	4.4	3.1	0.2
6 days	Inulin	7.0	4.5	0.3
30 "	White fir cellulose	8.9	3.6	0.2
25 "	Filter paper "	7.1	3.2	0.4
30 "	Hemicellulose	8.5	4.8	1.5

Tannase.

Tannase activity was determined by the action of the fungous meal on a 1 per cent solution of tannic acid. After 20 days incubation the cultures were filtered and 5 cc. of the filtrates were titrated against 0.05 N iodine. In all cases negative results were obtained.

Amidase and Urease.

Acetamide and urea were used as substrates to determine the presence or absence of enzymes which split amino-acids into ammonia and hydroxyl acids. The enzyme cultures were set up in wash bottles with the intakes and outlets sealed by means of rubber tubing and clamps. After 10 days incubation the bottles were connected up with other wash bottles containing distilled water and a few drops of bromothymol blue; air was then drawn through the series by means of a suction pump. The change in color due to the shifting of the hydrogen ion concentration and the length of time necessary to cause this change were noted.

When acetamide was used as a substrate, all tests were negative. With urea as a substrate, however, the color of the indicator changed from yellowish brown (pH 5.6) to bright blue in 3 seconds. In the tests in the controls a slight change in color was also noted, but in no case going beyond the light blue stage even after air had been drawn through the wash bottles for 3 minutes.

Rennet.

The presence of rennet has been variously reported in the wood-destroying fungi. In *Echinodontium tinctorium* fresh milk was coagulated in 2 hours while the controls remained unchanged.

Catalase.

When 50 cc. of a 3 per cent solution of hydrogen peroxide were added to 1 gm. of fungous meal, a rapid evolution of oxygen resulted amounting to 42 cc. of the gas in 1 minute.

Proteases.

Tryptic and ereptic fermentations were studied by the use of 1 per cent solutions of albumin, peptone, casein, and fibrin in enzyme cultures having neutral, acid, and alkaline reactions. In no case was a positive result obtained with either the biuret or the tryptophane test. In order to check the negative results in the fibrin, this material was stained with Congo red and the color fixed by immersing in boiling water. This stained fibrin was then used as a substrate. In such cultures a liberation of the stain would indicate the digestion of the fibrin. In the enzyme cultures having an alkaline reaction, a slight liberation of the stain was noted, but this also occurred in the alkaline controls. Biuret and tryptophane tests with these cultures also were negative.

SUMMARY.

In *Echinodontium tinctorium* the presence of the following enzymes was demonstrated: esterase, maltase, lactase, sucrase, raffinase, diastase, inulase, cellulase, hemicellulase, urease, rennet, and catalase.

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STUDIES IN THE PHYSIOLOGY OF THE FUNGI

VI. THE RELATION OF BACTERIA TO CELLULOSE FERMENTATION INDUCED BY FUNGI, WITH SPECIAL REFERENCE TO THE DECAY OF WOOD

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It is a matter of common observation and easy demonstration that bacteria are invariably present when wood decays under ordinary conditions. That a majority of these forms would be the ordinary air and soil saprophytes is only to be expected, yet the presence of cellulose-dissolving forms is not precluded. The purpose of this investigation is to determine whether or not cellulose-dissolving bacteria are habitually present on decaying wood under natural conditions and their influence, if any, on the rate of decay, also to determine whether or not the ordinary saprophytic forms, so universally present, in any way affect the cellulose-dissolving proclivities of the fungus actually causing the decay, by changing the reaction of the substratum so that it may be more or less favorable for optimum growth.

Due to the facts that all wood used in this work was first sterilized by autoclaving and that the theories regarding the effect of autoclaving wood are somewhat diverse, it was found desirable, if not expedient, to determine first whether or not this process of sterilizing wood produced new conditions, so that the results would not be comparable to those which might obtain under natural conditions.

SURVEY OF LITERATURE

EFFECTS OF AUTOCLAVING WOOD

The different viewpoints in regard to the effects of sterilization upon woody tissues are indicated by the works of Potter ('04) and Spaulding ('06). The earlier workers in this field were primarily interested in the determination of the chemical compounds present in woody tissues. Thus, Singer ('82) extracted four distinct substances by means of boiling water: vanillin, a substance giving the reactions of coniferin, a water-soluble gum, and also a substance giving a yellow color with hydrochloric acid. Van Wisselingh ('98) found that after treating slices of *Beta vulgaris* with distilled water at 125° C. for six hours a wall of pure cellulose remained, while the pectin substances were decomposed and dissolved. Even at a temperature of 100° C. the tendency for water to decompose and dissolve the cell wall was noted.

Potter ('04) tried the effect of hot water on different woods, *Quercus, Ulmus, Alnus, Aesculus,* and others, and found that steaming had a decided effect on the cell wall. It was shown that the action of boiling water caused a delignification of the xylem. The watery extract obtained from sawdust and fragments of wood when treated in this manner contained a substance which reacts to the lignin tests. Still further, it was shown that cold water, operating for a longer period of time, had a similar power of extracting from the xylem a substance which reacts with phloroglucin and thallin sulphate, and thus by continued soaking in water wood undergoes a partial delignification. If this be true, then autoclaving, even for the time required for sterilization, may have a marked effect on the wood when used for experimental purposes with reference to decay induced by fungi.

Rose and Lisse ('17) have made chemical analyses of sound Douglas fir and of the same wood in various stages of decay. Their results showed a rapid decrease in the percentage of cellulose as decay proceeded, while the lignin seemed to be far more resistant. They do not state what fungus caused the decay of the wood upon which they worked, and for that reason their results are far less valuable and can in no way be taken as general. It has been shown by von Schrenk ('00) that even on the same kind of wood two fungi may act in an entirely different manner with respect to which portion of the woody tissue is utilized. Thus, *Polyporus juniperinus* growing on the wood of *Juniperus virginiana* caused a delignification in the first stages of decay and the remaining wood fiber was completely reduced to cellulose. *Polyporus carneus,* on the other hand, almost entirely removed the cellulose when growing on the same wood.

Spaulding ('06) differs to some extent from the views expressed by Potter. Steaming tests were made with a variety of woods, thin sections being placed in the Arnold sterilizer or the autoclave and the effects noted by micro-chemical reactions. Spaulding obtained slight delignification in *Sassafras Sassafras* after fifteen hours of boiling, and in *Picea rubens* after seven hours in the autoclave or with interrupted boiling after a total of twenty-seven hours. With these two exceptions forty hours of boiling seemed to have no effect upon the lignin of the sections. In other tests, using the autoclave at a temperature of about 120° C., it was found that many woods gave evidences of delignification after fifteen hours of treatment, and nearly all after eighteen hours.

Spaulding, however, does not consider these effects important with reference to experimental work with the wood-decaying fungi, since it is claimed even the very thin sections had to be subjected to the action of boiling water for relatively long intervals before any decided effect could be detected. In discussing the effects of boiling water on finely divided wood, however, he admits that lignin is extracted in sufficient quantity for lignin reactions to be obtained in the filtrate from the extracted material. The effect of autoclaving thin shavings for one hour was also tested by Zeller ('17). It was found that the sections were not delignified to such an extent that by staining with zinc chloriodid any change could be detected, although the water in which the shavings had been boiled gave a very faint pink color with phloroglucin and hydrochloric acid.

THE RELATION OF BACTERIA TO CELLULOSE FERMENTATION

The fact that certain microörganisms have the power to dissolve cellulose has been known for some time. The actual determination of the forms involved and a better understanding of the process resulted from more recent investigations.

Mitscherlich ('50) first noted that the cellulose in the cell walls of slices of potato was dissolved when the slices were immersed in water and kept in a warm place for several days. A few years later attention was called by Haubner to the fact that it was impossible to recover more than 50 per cent of the crude fiber fed to ruminants. This observation was soon confirmed by numerous other workers, but the agent causing this reduction was unknown at that time. It has been recently demonstrated by Ellenberger ('15) and others that cellulose-dissolving ferments could not be extracted from the intestines of herbivorous animals, nor could any such ferments be obtained from the walls of the stomach or any of the secretive glands. The fungous flora of the intestines, however, showed numerous cellulose-dissolving organisms.

Some ten years after Haubner's discovery Trécul ('65) described a new genus, *Amylobacter,* which he found in connection with macerated plant tissues. Following this work numerous other workers described what they thought to be new forms. Thus we find *Bacterium navicula* of Reinke and Berthold ('79), the hydrogen and methane ferments of Omelianski, *Clostridium polymyxa, Vibrio rugula, Clostridium butyricum* of Prazmowski ('80), and others, all having the power to dissolve cellulose. At first there was considerable confusion regarding the validity of these forms. Van Tieghem ('77), working on Trécul's *Amylobacter,* found it to be a motile rod and called it *Bacillus amylobacter.* Prazmowski ('80) regarded his *Clostridium butyricum* as synonymous with *Vibrion butyrique* Pasteur, *Amylobacter* Trécul, *Bacillus amylobacter* Van Tieghem, and *Bacterium navicula* Reinke and Berthold. The work of Omelianski ('95, '97, '02, '04) greatly contributed to a clearer conception of the causative organisms in cellulose fermentation and a better understanding of the processes involved.

It is of special interest to note that *Bacillus amylobacter,* as shown by Van Tieghem ('77), does not dissolve the cellulose from all plants, and also the fact, as indicated by Omelianski, that with the forms worked on by him the power to dissolve cellulose decreased as the age of the cultures increased. McBeth and Scales ('13) found that cellulose-dissolving bacteria are universally present in cultivated soils.

That even the ordinary saprophytes may, under some conditions, affect some of the components of the cell wall, is shown by van Hall ('02). He found that *Bacillus subtilis* and *B. vulgatus* could produce a rot on potatoes, turnips, and various nuts at a temperature of from 37 to 42° C. and that the middle lamella was dissolved. Potter ('04) also found that in the decoction made by boiling the alburnum of oak wood *Bacillus subtilis* could grow and utilize the extracted substance (lignin).

EXPERIMENTAL WORK

THE EFFECTS OF AUTOCLAVING WOOD

Color changes induced in Douglas fir and western hemlock. —Equal amounts, 2.000 gms., of fine Douglas fir sawdust were placed in 125-cc. Erlenmeyer flasks and 25 cc. of distilled water were added to each. The flasks and contents were then weighed to the closest 0.1 gram preparatory to autoclaving, so that if any change in weight took place during autoclaving the flask could be restored to its original weight by the addition of distilled water, any change in the intensity of color then not being due to an increased concentration of the contents. The same methods were followed with western hemlock sawdust.

Some flasks and contents were not autoclaved; others were autoclaved for increasing intervals from forty-five minutes to twenty-one hours and the change of color noted. The colors are those of Ridgway ('12).

In both cases it is evident that a decided darkening occurs as the length of autoclaving increases. For the purposes of sterilization twenty hours of autoclaving are not necessary, yet there is a marked change in color caused by forty-five minutes of this treatment. The exact nature of these changes

TABLE I

COLOR CHANGES INDUCED BY AUTOCLAVING DOUGLAS FIR AND WESTERN HEMLOCK SAWDUST FOR VARIOUS INTERVALS

Interval of autoclaving	Color	
	Douglas fir	Western hemlock
Control (not autoclaved)	Antimony-yellow	Cinnamon-buff
45 minutes.............	Cinnamon-buff	Sayal-brown
10 hours...............	Cinnamon	Snuff-brown
20 hours...............	Mikado-brown	Natural brown

is not entirely known but it is quite evident that some changes must occur due to the prolonged heating.

Relative amounts of reducing substances in the aqueous extracts after autoclaving Douglas fir sawdust.—Into each of fifteen thoroughly cleaned 125-cc. Erlenmeyer flasks equal amounts, 2.000 gms., of fine Douglas fir sawdust were placed. The sawdust was prepared from the heart-wood in the following manner: Large pieces were sawed in the direction of the grain, resulting in a rather fine to coarse sawdust. This was then ground in a bone grinder until a comparatively fine mixture was obtained. The sawdust was dried to constant weight in a hot-air oven at a temperature of 85° C. and then allowed to stand uncovered in the laboratory for twenty-four hours. It was assumed that a fairly constant weight would be attained during that time, the amount of moisture taken up depending on the relative humidity of the air and the temperature. This procedure was followed rather than that of taking equal amounts of thoroughly dry sawdust, since it was found that a considerable fluctuation in weight took place during the process of weighing due to absorption of atmospheric moisture.

To each of the flasks 25 cc. of distilled water were added, and each flask and contents weighed, as before, to the nearest 0.1 gm., in order that the flasks might be restored to their original weight after autoclaving. Three of the fifteen flasks were not autoclaved, three were autoclaved 45 minutes, three 1 hour and 45 minutes, three 11 hours, and three 21 hours. After removal of the last set of flasks from the autoclave the contents of all the flasks were emptied into graduate cylinders and the total contents brought up to 80 cc. The extracts were then filtered through No. 4 Whatman filter-paper and the filtrate tested for reducing substances by Shaffer's ('14) method for the determination of sugars.

In table II the amounts of reducing substances, calculated as mgs. of copper, are given. Ten cc. of the sample were used in each case. The potassium permanganate solution used in the titration was 1/20 normal. The reduction value for the Fehling control has been subtracted.

TABLE II

AMOUNT OF REDUCING SUBSTANCES CALCULATED AS MILLIGRAMS OF COPPER IN 10 CC. OF THE AQUEOUS EXTRACTS

Flask no.	Interval of autoclaving	Amount of reducing substances in 10 cc. of the extracts	Average
45 46 47	Not autoclaved	2.22 2.22 2.22	2.22
1 2 3	45 minutes	5.88 6.04 5.72	5.88
4 5 7	1 hour, 45 minutes	7.68 7.52 7.68	7.63
8 9 10	11 hours	10.99 11.13	11.06
11 12 13	21 hours	20.98 21.08 18.76	20.27

It is clearly evident that the amount of reducing substances present in the aqueous extracts gradually increases with an increase in the time of autoclaving. It is quite probable also that some of the reducing power of the aqueous extracts is due to the presence of sugars. Fromherz ('07) has shown that on treating wood with hot water under pressure considerable quantities of sugar may be formed from the lignocelluloses and other wood components. It is claimed by Schwalbe ('11) that as pure a cellulose as cotton will yield considerable quantities of sugar when subjected to the same treatment.

Reducing substances in the extracts of Douglas fir after autoclaving and subsequent treatment with 0.5 per cent sulphuric acid.—The purpose of this series is to determine whether or not previous autoclaving in any way affects the rate of acid hydrolysis of woody tissues.

Flasks containing Douglas fir sawdust and distilled water were prepared and autoclaved as before. Enough c.p. sulphuric acid was then added to each flask to make it 0.5 per cent acid, and the entire series again autoclaved for 1 hour at 15 pounds pressure and the amounts of reducing substances determined as mgs. of copper.

TABLE III

AMOUNT OF REDUCING SUBSTANCES CALCULATED AS MILLIGRAMS OF COPPER IN 10 CC. OF THE EXTRACTS

Flask no.	Interval of autoclaving with dist. H_2O	Amount of reducing substance in 10 cc. of the extracts	Average
40 41	Not autoclaved	55.97 55.97	55.97
14 15	45 minutes	72.22 57.08	64.65
17 19	11 hours	58.83 58.83	58.83
23 24	21 hours	61.05 63.60	62.32

The results here show but a slight increase, if any, in the amounts of reducing substances present in the wood extracts in the flasks regardless of the increased time of autoclaving with distilled water. This may indicate either that prolonged previous treatment with distilled water did not cause any changes in the wood which would make it more subject to acid hydrolysis or that 0.5 per cent sulphuric acid is of sufficient concentration to hydrolyze the wood in any condition.

Reducing substances in the extracts of Douglas fir after autoclaving and subsequent treatment with 1.0 per cent sodium hydroxide.—Flasks containing 2.000 gms. of Douglas fir sawdust were prepared in exactly the same manner as in the two previous series. After autoclaving the flasks and contents for varying intervals with distilled water enough c. p. sodium hydroxide was added to each flask to make the contents 1.0 per cent alkaline, and the entire series was again autoclaved for one hour at fifteen pounds and the amount of reducing substances determined as mgs. of copper.

TABLE IV

AMOUNTS OF REDUCING SUBSTANCES CALCULATED AS MILLIGRAMS OF COPPER IN 10 CC. OF THE EXTRACTS

Flask no.	Interval of autoclaving with dist. H_2O	Amount of reducing substances in 10 cc. of the extracts	Average
43 44	Not autoclaved	6.99 7.63	7.31
25 27	45 minutes	4.08 4.40	4.24
28 29	11 hours	5.72 6.36	6.04
33 36	21 hours	9.54 9.38	9.46

Omitting those flasks which had no previous autoclaving there is a steady increase in the amount of reducing substances as the length of previous autoclaving increases. In this series different substances from those affected by acids would, of course, be acted upon. One to two per cent solutions of alkali, while having but little effect upon cellulose at temperatures considerably above 100° C., break down the pectic bodies and hydrolyze gums and resins which are but slightly affected with dilute acids.

Total amount of soluble substances present in the extracts.—Five cc. of the various wood extracts were placed in carefully cleaned, dry watch glasses. The liquid was evaporated in a hot-air oven at a temperature of 90° C., the heating being continued until the weight of the residue remained constant. The following table shows the total dry weight in 5 cc. of the extracts when the sawdust was autoclaved with distilled water for the time indicated:

TABLE V

TOTAL DRY WEIGHT OF THE SOLUBLE SUBSTANCES IN THE AQUEOUS EXTRACTS

Flask no.	Interval of autoclaving	Dry wt. of residue (gms.)	Average (gms.)
45	Not autoclaved	0.0045	
46		0.0045	
47		0.0047	0.0046
1	45 minutes	0.0078	
2		0.0072	
3		0.0077	0.0076
4	1 hour, 45 minutes	0.0076	
5		0.0075	
7		0.0075	0.0075
8	11 hours	0.0114	
9		0.0113	
10		0.0112	0.0113
11	21 hours	0.0149	
12		0.0137	
13		0.0143	0.0143

A considerable increase in the total soluble substances is evident. This is no doubt due in part to the dissolving out of initially soluble substances, but that it may also be partly due to the conversion of some of the wood substances is indi-

TABLE VI

TOTAL DRY WEIGHT OF THE SOLUBLE SUBSTANCES IN THE ACID EXTRACTS

Flask no.	Interval of autoclaving with dist. H_2O	Subsequent autoclaving after addition of acid	Dry wt. of residue (gms.)	Average (gms.)
39	Not autoclaved	1 hour	0.0169	
40			0.0173	
41			0.0199	0.0180
14	45 minutes	1 hour	0.0073	
15			0.0045	
16			0.0079	0.0066
17	11 hours	1 hour	0.0088	
19			0.0080	
21			0.0075	0.0081
22	21 hours	1 hour	0.0177	
23			0.0193	
24			....	0.0185

cated by the table showing a similar increase in the amounts of reducing substances present.

The same procedure was followed with the extracts containing 0.5 per cent sulphuric acid. Table vi shows the dry weight of the total soluble substances after the weight of sulphuric acid had been deducted in each case. Each individual watch glass was weighed immediately after taking out of the oven, to avoid the error which might be caused by the acid taking up atmospheric moisture.

Table vii shows the total dry weight of the soluble substances present in the alkaline extracts after the amount of sodium hydroxide in the residue had been deducted in each case.

TABLE VII

TOTAL DRY WEIGHT OF THE SOLUBLE SUBSTANCES IN THE ALKALINE EXTRACTS

Flask no.	Interval of autoclaving with dist. H_2O	Subsequent autoclaving after addition of alkali	Dry wt. of residue (gms.)	Average (gms.)
42	Not autoclaved	1 hour	0.0366	
43			0.0312	
44			0.0333	0.0337
25	45 minutes	1 hour	0.0384	
26			0.0385	
27			0.0377	0.0382
28*	11 hours	1 hour	0.0100	
29*			0.0029	
31			....	0.0064
32	21 hours	1 hour	0.0383	
33			0.0415	
36			0.0413	0.0404

* Portion of extract lost in oven.

Here again a slight increase is noted as the interval of autoclaving with distilled water increased.

Relative amounts of tannins present in the aqueous extracts.—It could legitimately be contended that the increase in the amounts of reducing substances present in the extracts which reduce Fehling's solution might merely be due to prolonged boiling extracting greater amounts of tannin. With this in mind the aqueous extracts were treated with a solution of ferric chloride and the intensity of the color taken as a criterion of the relative amounts of tannins present. Five cc. of the various aqueous extracts were placed in clean test-tubes of 18 mm. diameter, four drops of a 2.0 per cent aqueous solution of ferric chloride added to each, and the color determined by comparing them with Ridgway's ('12) plates.

TABLE VIII

RELATIVE AMOUNTS OF TANNINS PRESENT IN THE AQUEOUS EXTRACTS

Flask no.	Interval of autoclaving	Color	Order of intensity
45, 46, 47	Not autoclaved	Wood-brown	3
1, 2, 3	45 minutes	Yew-green	1
4, 5, 7	1 hour, 45 minutes	Krönberg's green	2
8, 9, 10	11 hours	Wood-brown	3
11, 12, 13	21 hours	Wood-brown	3
Control (distilled water)	....	Yellow tint	....

This would seem to indicate that the extracts from the wood autoclaved the longest intervals and the extract from the wood not autoclaved contained the least tannin, while that autoclaved for forty-five minutes contained the most. Comparing these results with the table showing the amounts of reducing substances in the various aqueous extracts it is found that they in no way coincide.

The presence of lignin in the aqueous extracts.—A test for the presence of lignin in the various aqueous extracts was made with phloroglucin and hydrochloric acid. In no case was more than a faint pink color evident. When, however, a few cc. of ether were added, the mixture well shaken, the ether separated and evaporated, the residue gave a decided red color with phloroglucin and hydrochloric acid. All of the extracts gave a positive test when treated in this manner.

The presence of coniferin in the aqueous extracts.—When an aqueous solution of phenol and hydrochloric acid was added to the extracts in no case did a color reaction take place.

Hydrogen ion concentration of the aqueous extracts.—The hydrogen ion concentration of the extracts was determined according to the method suggested by Sörensen ('09) as modified by Henderson ('09) and previously employed by Duggar in this laboratory. The following table gives the results of these determinations:

TABLE IX
HYDROGEN ION CONCENTRATION OF THE AQUEOUS EXTRACTS

Flask no.	Interval of autoclaving	Hydrogen ion concentration
45, 46, 47............	Not autoclaved	10^{-7}
1, 2, 3...............	45 minutes	10^{-6}
4, 5, 7...............	1 hour, 45 minutes	10^{-6}
8, 9, 10..............	11 hours	10^{-5}
11, 12, 13............	21 hours	10^{-4}

The extract from the unautoclaved Douglas fir sawdust is practically neutral. With the autoclaved sawdust there is a decided increase in the hydrogen ion concentration in the aqueous extracts as the interval of autoclaving increases.

Acidity of the aqueous extracts.—The extracts were also titrated against N/20 sodium hydroxide with the following results. The acidity is expressed according to Fuller's scale, each being the average of three titrations.

TABLE X
DEGREE OF ACIDITY OF THE AQUEOUS EXTRACTS

Flask no.	Interval of autoclaving	Acidity
46, 47...............	Not autoclaved	1.0
2, 3...............	45 minutes	1.0
5, 7...............	1 hour, 45 minutes	2.0
8, 9...............	11 hours	3.0
12, 13...............	21 hours	4.0

These results correspond with the hydrogen ion determinations. A gradual increase in acidity results from increased length of autoclaving.

Effect of autoclaving on the rate of decay induced by fungi.—In order to determine whether or not autoclaving in any way affected the rate of decay induced by fungi approximately equal amounts of western hemlock sawdust were placed in 125-cc. wide-necked bottles. The bottles and contents were placed in the hot-air oven and dried to constant weight at a temperature of 90° C. and then weighed. Approximately equal amounts of distilled water were added to each bottle and they were then autoclaved for periods from 45 minutes to 20 hours.

The bottles in which the contents were not autoclaved were treated as follows: After drying to constant weight in the hot-air oven they were plugged with previously sterilized plugs. Weighing was done with the plugs removed, every precaution being taken to avoid contamination. Sterile distilled water was then added and they were ready for inoculation. Portions of the contents of three test bottles treated in this manner were poured on sterile agar plates and in each case they were found to be sterile.

All bottles were inoculated with *Fomes pinicola* and the rate of decay determined by the loss in weight of the sawdust at the end of four months. The inoculations were made on April 16, 1917. On August 18, 1917, the plugs were removed and the contents again dried to constant weight and the loss in weight determined. Each series contained eight cultures.

The details of this work are discussed under the relation of bacteria to the rate of decay induced by fungi.

Table XI clearly shows that autoclaving western hemlock has a marked effect on the rate of decay induced by *Fomes pinicola*. It is quite probable that for different fungi the effect might be quite different. In this case a gradual increase in the rate of decay is noted with an increase in time of autoclaving up to ten hours. After twenty hours of autoclaving the fungus did not attack the wood even though each bottle, in this case, was inoculated the second time. There was no growth of the fungus from the immediate point of inoculation, and when, at the time of the second inoculation, 30 days after the first, the small mass of fungus and agar used for the first inoculation was removed from the bottles and transferred to agar slants the fungus was found to be dead. At some point between ten and twenty hours' autoclaving a decided change in the sawdust must have taken place which made it toxic to the fungus. Just what this change was is not known. Suffice it here to say that when rate of decay induced by fungi is studied the time of autoclaving of the wood must also receive due consideration.

TABLE XI

THE EFFECT OF AUTOCLAVING WESTERN HEMLOCK ON THE RATE OF DECAY INDUCED BY FOMES PINICOLA

I	II	III	IV	V	VI	VII	VIII
Culture bottle	Weight of sawdust before decay (gms.)	Weight of sawdust after decay (gms.)	Loss in weight (gms.)	Loss (per cent)	Average loss (per cent)	Time of autoclaving	Remarks
434	7.34	7.33	0.01	0.13		Not autoclaved	Only slight growth of fungus near point of inoculation.
655	7.16	7.16	0.00	0.00			
242	7.58	7.58	0.00	0.00			
160	7.25	7.25	0.00	0.00			
106	6.96	6.96	0.00	0.00			
582	7.21	7.21	0.00	0.00	0.01		
16	7.19	7.18	0.01	0.14		45 minutes	Light growth on surface.
558	7.90	7.89	0.01	0.13			
741	7.71	7.71	0.00	0.00			
595	8.94	8.92	0.02	0.22			
244	7.46	7.44	0.02	0.27	0.15		
724	8.09	8.07	0.02	0.23		5 hours	Light growth throughout entire mass of sawdust.
598	7.00	6.96	0.04	0.57			
99	6.86	6.82	0.04	0.58			
209	7.49	7.42	0.07	0.93			
120	7.47	7.42	0.05	0.67			
762	7.67	7.62	0.05	0.65			
652	6.88	6.87	0.01	0.14	0.54		
739	6.95	6.35	0.60	8.63		10 hours	Heavy growth throughout entire mass of sawdust.
744	6.64	6.48	0.16	2.41			
647	7.50	7.32	0.18	2.40			
261	6.81	6.74	0.07	1.03			
602	7.59	7.57	0.02	0.26			
477	7.30	7.26	0.04	0.55			
98	7.40	7.34	0.06	0.81	2.30		
683	7.13	7.13	0.00	0.00		20 hours	All bottles inoculated twice. In neither case did infection take place.
408	7.31	7.31	0.00	0.00			
95	7.17	7.17	0.00	0.00			
579	7.23	7.22	0.01	0.14			
644	7.54	7.54	0.00	0.00			
610	7.31	7.31	0.00	0.00			
154	7.53	7.53	0.00	0.00	0.01		
1051	9.37	9.37	0.00	0.00		Control	Error due to weighing ± 0.02 per cent.
1052	8.53	8.53	0.00	0.00			
1053	9.11	9.11	0.00	0.00			
1054	8.60	8.60	0.00	0.00			
1055	7.32	7.32	0.00	0.00			
1056	7.47	7.46	0.01	0.13			
1057	9.23	9.23	0.00	0.00			
1058	6.04	6.04	0.00	0.00			
1059	8.53	8.53	0.00	0.00			
1060	9.16	9.15	0.01	0.11	0.02		

BACTERIA IN RELATION TO CELLULOSE FERMENTATION AS INDICATED BY THE DECAY OF WOOD

Isolation of bacteria present on decaying wood under natural conditions and the determination of their cellulose-dissolving properties.—It has been satisfactorily demonstrated by numerous investigators that certain bacteria have the power to dissolve cellulose under both aërobic and anaërobic conditions. If these forms play any part in the decay of wood under natural conditions they should be found present in connection with the fungi or alone on decaying wood. To determine this the bacteria from numerous samples of decaying wood were isolated and their cellulose-dissolving properties investigated.

Method of isolation.—Small samples of decaying wood were placed in test-tubes containing about 10 cc. of sterile distilled water and allowed to soak from five to ten minutes with frequent vigorous shakings of the tube to facilitate removing any bacteria which might adhere to the surface of the samples. Transfers were made from the water blanks to tubes of melted media and plated in the usual manner.

The following kinds of media were employed: hard potato agar, cotton cellulose agar, filter-paper cellulose agar, oak cellulose agar, ash cellulose agar, Douglas fir cellulose agar, and western hemlock cellulose agar.

The hard potato agar had the following composition:

Extract from	200 gms. potato
Glucose	20 gms.
Agar	20 gms.
Distilled water to make	1000 cc.

The filter-paper cellulose was prepared in the manner described by McBeth and Scales ('13) and later by Cooley ('14). Fifteen gms. of filter-paper were dissolved in Schweitzer's solution and precipitated with hydrochloric acid. The mixture was diluted to ten liters and the cellulose allowed to settle. After settling, the supernatant liquid was poured off and the cellulose thoroughly washed with hydrochloric acid to get rid of all traces of copper. It was then thoroughly washed with distilled water to remove all traces of chlorine. The water was filtered off with a Buchner's funnel and the cellulose washed repeatedly. After washing, it was transferred to a liter flask containing 500 cc. of distilled water, and sterilized.

Cotton cellulose was prepared in the same manner as the above.

The wood cellulose was prepared by treating a quantity of fine shavings of the wood in question with a solution composed of 30 gms. of potassium chlorate dissolved in 520 cc. of nitric acid (sp. gr. 1.1). The shavings were added slowly to the solution while the flask was immersed in ice water to prevent excessive heating. After the addition of the shavings the mixture was kept cool for four to five weeks when the shavings were well washed and then dissolved in Schweitzer's solution in the same manner as was the filter-paper and the cotton.

Cellulose agar was prepared by adding about 1 per cent (by weight) of the precipitated celluloses to a mineral nutrient solution having the following composition:

Monopotassium phosphate	1 gm.
Magnesium sulphate	1 gm.
Sodium chloride	1 gm.
Ammonium sulphate	1 gm.
Calcium carbonate	2 gms.
Distilled water	1000 cc.

Twenty gms. of agar were added to a mixture containing 500 cc. of the above solution and 500 cc. of the cellulose suspension.

It is evident that the cellulose present in media made up in this manner is the only source of carbon. Growth of an organism, therefore, on the medium may be taken as an indication of the power to utilize cellulose. Table XII indicates the results of the attempts to isolate cellulose-dissolving organisms from decaying wood. The cellulose agar plates were kept under observation from two to three weeks at room temperature.

In no case was a bacterial form found on any of the cellulose agars. The fact that none developed, however, does not preclude the possibility of their presence on the decaying wood. It is a known fact that some organisms require the presence

TABLE XII

ISOLATION OF CELLULOSE-DISSOLVING BACTERIA FROM DECAYING WOOD

Sample no.	Place of collection	Date of collection	Kind of wood	No. of bacterial colonies on Thaxter's agar	Number of colonies on cellulose agar					
					Filter paper	Cotton	Ash	Oak	Douglas fir	Western hemlock
1	St. Louis	10/ 3/16	Willow	0	0	0	0	0	0	0
2		10/ 3/16	Willow	8	0	0	0	0	0	0
3		11/24/16	Locust	4	0	0	0	0	0	0
4		11/24/16	Locust	6	0	0	0	0	0	0
5		11/24/16	Ash	3	0	0	0	0	0	0
6		11/24/16	Osage orange	9	0	0	0	0	0	0
7		11/24/16	Juniper	2	0	0	0	0	0	0
8		11/24/16	Oak	3	0	0	0	0	0	0
9		11/24/16	Oak	2	0	0	0	0	0	0
10		11/27/16	Palm stem	5	0	0	0	0	0	0
11	Seattle	10/10/16	Douglas fir	2	0	0	0	0	0	0
12		10/10/16	Douglas fir	0	0	0	0	0	0	0
13		10/10/16	Douglas fir	0	0	0	0	0	0	0
14		10/10/16	Douglas fir	0	0	0	0	0	0	0
15		10/10/16	Douglas fir	3	0	0	0	0	0	0
16		10/10/16	Douglas fir	7	0	0	0	0	0	0
17		10/10/16	Douglas fir	4	0	0	0	0	0	0
18		10/10/16	Douglas fir	6	0	0	0	0	0	0
19		10/10/16	Western hemlock	7	0	0	0	0	0	0
20		10/10/16	Western hemlock	0	0	0	0	0	0	0
21		10/10/16	Western hemlock	2	0	0	0	0	0	0
22		10/10/16	Western hemlock	3	0	0	0	0	0	0
23		10/10/16	Western hemlock	0	0	0	0	0	0	0
24		10/10/16	Western hemlock	1	0	0	0	0	0	0
25		10/10/16	Western hemlock	3	0	0	0	0	0	0
26		10/10/16	Western hemlock	3	0	0	0	0	0	0
27		10/10/16	Western hemlock	2	0	0	0	0	0	0
28		10/10/16	Western hemlock	1	0	0	0	0	0	0
29		10/10/16	Western hemlock	0	0	0	0	0	0	0
31		10/10/16	Western hemlock	4	0	0	0	0	0	0
32	St. Louis	10/10/16	Ash	1	0	0	0	0	0	0
33		10/10/16	Ash	4	0	0	0	0	0	0
34		10/10/16	Maple	3	0	0	0	0	0	0
35		10/10/16	Maple	5	0	0	0	0	0	0

of small quantities of other carbohydrates in their early stages of development before cellulose can be utilized. In many of the plates species of *Penicillium* developed which dissolved the cellulose to a considerable extent. This could be determined by the clearing up of the agar near the colonies. That some species of *Penicillium* have this power has been shown by Ward ('98) and McBeth and Scales ('13).

RELATION OF BACTERIA TO THE RATE OF DECAY INDUCED BY FUNGI UNDER LABORATORY CONDITIONS

It is possible that even though the cellulose-dissolving bacteria play no part in the decay of wood under natural conditions, the ordinary air, soil, and water forms, so universally found in connection with decaying wood, may have an important indirect influence on the rate of decay caused by fungi. This may come about by these organisms changing the reaction of the substratum in such a manner that it may be more or less favorable to the optimum development of the fungus; or it is also quite possible that in their metabolism they may utilize some of the hydrolytic products produced by the fungus, an accumulation of which might be partially toxic to the fungus. In order to determine whether or not this is true, pure cultures of bacteria were added to pure cultures of different fungi and their effect, if any, on the rate of decay noted.

Methods and materials.—Approximately equal amounts of sawdust were placed in clean weighed 125-cc. wide-necked bottles. The bottles and contents were placed in a hot-air oven and dried to constant weight at a temperature of 90° C. and weighed again. Approximately equal amounts of water were added to each flask and they were then plugged and sterilized at fifteen pounds for twenty minutes. Every effort was made to have conditions as nearly identical as possible in each bottle. Each was inoculated with a wood-destroying fungus, and after the wood was well infected bacteria were added and the rate of decay determined by the loss in weight of the culture bottles after six months.

The experiments were conducted with four species of commercial woods, Douglas fir (*Pseudotsuga taxifolia*), western hemlock (*Tsuga heterophylla*), white ash (*Fraxinus sp.*), and red oak (*Quercus sp.*). Heart-wood was used in each instance. The Douglas fir and western hemlock wood were obtained from freshly sawed logs. The white ash and red oak were purchased from lumber dealers and were in all probability air-seasoned. The sawdust was prepared as previously discussed.

CULTURE RELATIONS: FUNGI

The three fungi used were selected because of their vigorous growth in cultures, their importance as wood-destroying forms, and the fact that they are found on both coniferous and deciduous hosts. *Fomes pinicola* Fr. is particularly destructive on a great variety of conifers. It has also been reported by Weir ('14) on *Populus trichocarpa, P. tremuloides, Betula occidentalis, Fagus sylvatica, Quercus pendiculata,* and other deciduous hosts. *Polystictus versicolor* (L.) Fr. has a wide range of deciduous hosts and has also been reported by Weir ('14) on *Larix occidentalis, Pinus monticola,* and *Pseudotsuga taxifolia. Lenzites saepiaria* Fr. has been previously used in this laboratory by Zeller ('16) with excellent results. It is more important as an organism causing decay of coniferous woods but has also been reported on *Populus alba, P. tremuloides, Betula occidentalis, Acer glabrum,* and other deciduous hosts by Weir ('14).

Cultures of *Fomes pinicola* were made from young sporophores by the tissue method first reported by Duggar ('05) and later used by Zeller ('16) in obtaining cultures of *Lenzites saepiaria.* Young sporophores, from four to six inches in diameter, were washed with tap water followed by a thorough washing with sterile distilled water, and then dried with sterile tissue towelling. An incision from one-half to one centimeter deep was made across both surfaces of the sporophore with a sterile scalpel and the sporophore then broken open. This eliminated the possibility of contamination of the deeper tissue by the carrying down by the scalpel of bacteria and spores from the surface of the sporophore and also left a jagged surface on the broken deeper tissues, portions of which were easily torn off by means of a sterile forceps and quickly transferred to Thaxter's hard agar slants. The fungus grew exceptionally well on this media. Twenty-four tissue transfers were made, of which twenty-three grew, none being contaminated.

Cultures of *Lenzites* and *Polystictus* were made by the spore method. This method has been extensively used by Falck ('02), Lyman ('07), Münch ('09), and Zeller ('16). The technique involved in making spore cultures of the two forms is similar. The sporophores were thoroughly rinsed with sterile distilled water to remove as many bacteria and foreign spores of fungi as possible. Since gentle agitation facilitates this, it was found convenient to place the sporophores in sterile wide-necked flasks partially filled with sterile distilled water. After a gentle shaking the sporophores were removed with a pair of sterile forceps, dried with sterile tissue towelling and placed in other similar flasks. By repeating this process three times the surface of the sporophore is found to be comparatively free from bacteria and the spores of foreign fungi. Following this preliminary washing the sporophores were allowed to soak from one to two hours in sterile distilled water, then thoroughly rinsed and dried as before, and finally placed hymenium downward in large sterile Petri dishes. By means of short sterile glass rods the sporophore was kept from resting on the bottom of the Petri dish and thus the possibility of contamination of the Petri dish by contact with the sporophore was avoided. In from twelve hours to two days the spores were discharged to such an extent that they were plainly visible on the bottom of the Petri dish. By means of a platinum loop they were removed to a sterile water blank and by the same method were transferred from the water blank to tubes of molten agar and then plated in the usual manner. Transfers were made from characteristic colonies from the plates to agar slants.

A much easier and quicker method, though less certain to be a pure culture, is to place the washed sporophores in Petri dishes containing a small amount of sterile agar. The sporophores are not allowed to rest directly on the agar but are kept from it by means of short sterile glass rods lying across the agar. The spores thus fall directly on the nutrient agar and after germination transfers can be made directly to agar slants. Cultures free from contamination were obtained by this method but were not used on account of the decided advantages of the other method.

In order to avoid growing the fungi on artificial media for any length of time before using them in the decay experiments, they were transferred to sterile Douglas fir and hemlock sawdust in Erlenmeyer flasks for keeping. All three forms grew comparatively well on both kinds of sawdust.

Optimum degree of acidity of media for fungi used.—In connection with this work it was necessary to determine whether or not slight changes in the reaction of the medium had any influence on the rate of growth of the fungi. Media of different degrees of acidity were therefore made up. Three liters of medium having the following composition per liter were prepared:

Extract from 450 gms. carrot	
Glucose	10 gms.
Agar	25 gms.
Distilled water to make..	1000 cc.

Two-hundred-cc. amounts of this medium were placed in 500-cc. Erlenmeyer flasks and autoclaved for twenty minutes at fifteen pounds. This medium titrated +13.5 Fuller's scale after autoclaving. After adding varying amounts of sterilized hydrochloric acid or sodium hydroxide to the flasks samples were again titrated while the agar was still in a liquid condition. Twenty-cc. amounts were placed in each of six Petri dishes of approximately nine centimeters diameter. Before inoculating these plates with the fungi they were allowed to stand for three days at room temperature in order to determine whether or not they were sterile. For each fungus two plates were used for each concentration. The colonies were measured in two directions at right angles to each other and the average taken.

It was endeavored to inoculate all plates in a practically identical manner, and to do this, plate cultures of the fungus in question were cut by means of a sterile scalpel into squares measuring approximately three-quarters of a centimeter on each side. A single square was placed in the center of each plate and after six and again after eight days' incubation at room temperature the size of the colonies was measured. The results are tabulated in table XIII:

TABLE XIII

RATE OF GROWTH OF FOMES PINICOLA, POLYSTICTUS VERSICOLOR, AND LENZITES SAEPIARIA ON MEDIA OF INCREASING ACIDITY

Reaction of media, Fuller's scale	Diameter of colonies in centimeters					
	Fomes pinicola		Polystictus versicolor		Lenzites saepiaria	
	6 days	8 days	6 days	8 days	6 days	8 days
+ 2.5	No growth	1.8	No growth	1.6	No growth	2.3
+ 4.5	1.8	3.0	4.9	7.0	2.3	3.7
+ 6.0	1.9	3.1	5.4	7.6	2.4	3.9
+ 7.75	2.0	3.1	6.3	8.3	2.4	3.9
+ 9.75	1.9	3.1	6.6	9.3	3.2	4.1
+13.5	2.1	3.3	5.7	7.4	2.4	4.0
+14.0	1.9	3.1	5.8	7.4	2.5	4.0
+16.25	1.8	2.9	5.3	6.9	2.6	3.9
+18.5	1.7	2.9	5.1	6.4	2.7	4.1
+21.25	1.8	3.0	4.7	6.0	2.5	3.9
+22.25	1.6	3.0	4.4	5.7	2.3	3.3
+24.5	1.7	3.0	4.3	4.6	2.1	2.8

There is but little difference in the rate of growth of *Fomes pinicola* on media ranging from + 5 to + 24.5 acid, Fuller's scale. On a medium of + 2.5 there is a decided retardation in the rate of growth. *Polystictus versicolor* shows a marked response to the reaction of the medium. A maximum is attained when the medium titrates + 9.75, Fuller's scale, with a steady decrease in the rate of growth as the acidity increases. The effect of the reaction of the medium on the rate of growth of *Lenzites saepiaria* is quite similar to that on *Fomes pinicola* except that there is a marked retardation on the media of the higher concentrations.

It is appreciated that by titrating samples of acidified agar in this manner the actual acidity of the medium is not definitely determined, due to the buffer effect of the agar on the hydrogen ions; yet the results would indicate that slight variations in the reaction of the substratum would have little or no effect on the rate of development of *Fomes pinicola* or *Lenzites saepiaria* but that they might have in the case of *Polystictus versicolor.*

CULTURE RELATIONS: BACTERIA

The bacteria used were chosen, with one exception, with reference to their acid or alkaline reactions on culture media. The presence of a nitrogen-fixing soil form was also tried. The nomenclature used is that of Migula ('00). The following organisms were employed:

(1) Alkaline on litmus milk.
 Bacillus vulgatus (Flügge) Mig.
 Bacterium mycoides (Scholl) Mig.
(2) Acid on litmus milk.
 Bacillus vulgaris (Hauser) Mig.
 Bacillus coli (Escherlich) Mig.
 Bacillus prodigiosus (Ehrenberg) Flügge.
(3) Nitrogen-fixing form.
 Azotobacter chroococcum Beijerinck.

All forms were plated in the usual manner, to make certain that pure cultures were being considered, and then transferred to standard beef broth.

Method of inoculation of culture bottles.—Transfers from the sawdust cultures of the fungi were made to sterile agar plates. When the entire surface of the plate was overgrown with the mycelium it was cut into small squares of approximately one square centimeter size by means of a sterile scalpel. A single square was added to each culture bottle. In most cases the mycelium could be seen growing through the sawdust about one week after inoculation.

When the fungus mycelium had become well established in the sawdust the culture bottles were inoculated a second time either with another fungus or with bacteria. Previous to this second inoculation all culture bottles were carefully inspected and those in which the infection of the sawdust did not occur were thrown out. The second fungus inoculation was made in a similar manner to the first. The bacteria were added by transferring a considerable number of the organisms from hard agar slants to 250-cc. Erlenmeyer flasks containing distilled water. Where more than one bacterium was added to the culture bottles a mixture of the organisms was made in the same way. Approximately one cc. of bacterium suspension was added to each culture bottle. After all of the culture bottles were inoculated with the bacterial suspension transfers were made to agar slants to make certain that the action of the distilled water had not killed the organisms. In the case of the controls and bottles which contained the fungi alone a similar amount of sterile distilled water was added so that the moisture conditions in all the culture bottles would be the same.

After all of the culture bottles were inoculated with the desired organisms the cotton plug of each was covered with two thicknesses of paraffined tissue paper to avoid excessive evaporation from the flasks, the paper being secured by means of a rubber band. This did not make an air-tight covering, but in most cases the cultures remained sufficiently moist without watering throughout the period of incubation. In the few cases in which additional watering was necessary effort was made to keep the moisture conditions similar to those of the other culture bottles.

The cultures were then removed to a very humid rotting-pit with a temperature varying from 22° C. in summer to 35° C. in winter. The period of incubation in all cases was six months.

At the end of the period of incubation small particles of sawdust, such as would adhere to a moist sterile platinum needle were transferred to sterile potato agar slants in order to determine whether or not the bacteria were still alive. The plugs were then removed and the culture bottles again dried to constant weight in the hot-air oven at a temperature of 90° C., weighed, and the loss in weight determined.

In all cases the rate of decay is based on the loss in weight of the culture bottles during the period of incubation. Each set originally contained ten cultures but some were thrown out, due to infection of the fungus not taking. The average loss in each set was determined and taken as the basis of comparison between the various sets.

DESCRIPTION OF CULTURE SERIES

Four series of cultures were prepared: series A, of red oak; series B, of white ash; series C, of western hemlock; and series D, of Douglas fir.

Culture bottles from which transfers were made to determine the presence or absence of bacteria at the end of the period of incubation are indicated by the symbols designated in the footnotes in the following tables:

TABLE XIV (Series A)

THE EFFECT OF BACTERIA ON THE RATE OF DECAY INDUCED BY FOMES PINICOLA, POLYSTICTUS VERSICOLOR, AND LENZITES SAEPIARIA ON RED OAK

I	II	III	IV	V
Culture bottle	Weight of sawdust before decay (gms.)	Weight of sawdust after decay (gms.)	Loss in weight due to decay (gms.)	Loss due to decay (per cent)
Control, error due to weighing ±0.02%				
71	8.37	8.36	0.01	0.12
72	7.98	7.98	0.00	0.00
73	7.41	7.41	0.00	0.00
74	9.00	9.00	0.00	0.00
75	8.96	8.96	0.00	0.00
76	9.51	9.50	0.01	0.10
77	7.39	7.39	0.00	0.00
78	7.56	7.56	0.00	0.00
79	8.09	8.09	0.00	0.00
80	9.16	9.16	0.00	0.00
Average	......	......	......	0.02
Fomes pinicola 2/16/17				
1	9.44	9.41	0.03	0.32
2	9.47	9.47	0.00	0.00
3	9.45	9.45	0.00	0.00
4	8.71	8.70	0.01	0.11
5	8.87	8.84	0.03	0.38
6	8.83	8.83	0.00	0.00
7	9.51	9.48	0.03	0.31
8	9.03	9.03	0.00	0.00
9	9.34	9.33	0.01	0.11
10	9.00	9.00	0.00	0.00
Average	......	......	......	0.10
F. pinicola 2/16/17, *P. versicolor* 3/29/17				
11	8.75	8.72	0.03	0.34
12	9.22	9.20	0.02	0.21
13	9.42	9.39	0.03	0.32
14	9.11	9.09	0.02	0.22
15	......	......	......	......
16	......	......	......	......
17	9.89	9.78	0.11	1.11
18	9.26	9.26	0.00	0.00
19	9.12	9.07	0.05	0.55
20	9.95	9.92	0.03	0.30
Average	......	......	......	0.36
F. pinicola 2/16/17, *L. saepiaria* 3/30/17				
21	9.52	9.50	0.02	0.21
22	9.79	9.75	0.04	0.40
23	......	......	......	......
24	10.05	10.04	0.01	0.10
25	9.53	9.49	0.04	0.60
26	10.30	10.25	0.05	0.48
27	9.69	9.67	0.02	0.21
28	9.32	9.30	0.02	0.21
29	10.15	10.14	0.01	0.10
30	......	......	......	......
Average	......	......	......	0.29
F. pinicola 2/16/17, *P. versicolor* & *saepiaria* 3/30/17				
31	9.53	9.32	0.21	2.22
32	8.72	8.61	0.11	1.26
33	9.47	9.27	0.20	2.11
34	10.26	10.20	0.06	0.58
35	9.02	8.90	0.12	1.33
36	9.36	9.20	0.16	1.70
37	9.41	9.35	0.06	0.63
38	9.96	9.91	0.05	0.50
39	9.71	9.53	0.18	1.85
40	9.55	9.52	0.03	0.31
Average	......	......	......	1.24
F. pinicola 2/16/17, *B. prodigiosus* 3/30/17				
41	9.23	9.18	0.05	0.54
42	9.35	8.95	0.40	4.27
43	9.94	9.86	0.08	0.80
44	8.70	8.43	0.27	3.08
45	9.45	9.26	0.19	2.01
46	8.97	8.91	0.06	0.67
47*	9.12	8.99	0.13	1.42
48	9.42	9.20	0.22	2.46
49*	9.14	9.04	0.10	1.09
50*	9.33	9.19	0.14	1.60
Average	......	......	......	1.79

* No bacteria present at end of incubation.

TABLE XIV (Continued)

I	II	III	IV	V	I	II	III	IV	V
F. pinicola 2/16/17, *Bact. mycoides* 3/31/17					*L. saepiaria* 2/15/17, *Bact. mycoides* 3/31/17				
51	9.47	9.16	0.31	3.37	102*	8.48	8.43	0.05	0.59
52	9.36	9.15	0.21	2.23	103	8.75	8.72	0.03	0.34
53	10.22	10.04	0.18	1.86	104	8.92	8.92	0.00	0.00
54	10.15	10.00	0.15	1.08	105	8.78	8.67	0.11	1.25
55	9.99	9.93	0.06	0.60	107	8.36	8.34	0.02	0.23
56*	9.25	9.06	0.19	2.06	108*	8.64	8.64	0.00	0.00
57	9.58	9.38	0.20	2.09	109	8.91	8.79	0.12	1.35
58	9.24	8.99	0.25	2.81	110*	8.26	8.20	0.06	0.72
59*	9.37	9.14	0.13	1.38					
60*	9.91	9.67	0.24	2.52					
Average				2.00	Average				0.56
F. pinicola 2/16/17, *B. prodigiosus* & *Bact. mycoides* 3/31/17					*L. saepiaria* 2/5/17, *B. prodigiosus* & *Bact. mycoides* 3/31/17				
61	9.74	9.49	0.25	2.57	111	9.22	9.22	0.00	0.00
62	9.90	9.69	0.21	2.12	113*	8.57	8.57	0.00	0.00
63*	8.98	8.75	0.23	2.56	116	9.93	9.86	0.07	0.75
64*	9.79	9.54	0.25	2.55	117*	9.73	9.61	0.12	1.23
65	9.59	9.49	0.10	1.04	118	9.49	9.48	0.01	0.11
66*	8.69	8.57	0.12	1.38	119	8.38	8.38	0.00	0.00
67	9.74	9.67	0.07	0.71	121	7.85	7.85	0.00	0.00
68	10.02	9.73	0.29	2.89	122*	8.89	8.89	0.00	0.00
69	9.01	8.82	0.19	2.12					
70	11.17	10.97	0.20	1.79					
Average				1.97	Average				0.25
Lenzites saepiaria 2/15/17					*L. saepiaria* 2/5/17, *B. vulgatus* & *Bact. mycoides* 4/2/17				
81	9.19	9.18	0.01	0.11	883*	10.94	10.90	0.04	0.36
82	8.87	8.78	0.09	1.01	885	9.66	9.55	0.11	1.14
83	8.75	8.74	0.01	0.11	887†‡	10.23	10.06	0.17	1.66
84	10.73	10.72	0.01	0.09	888†‡	9.06	9.03	0.03	0.33
85	10.27	10.27	0.00	0.00	889	8.80	8.78	0.02	0.23
86	8.99	8.98	0.01	0.11	890	8.72	8.68	0.04	0.46
87	8.42	8.42	0.00	0.00					
88	8.61	8.60	0.01	0.12					
89	9.32	9.30	0.02	0.22					
90	9.45	9.44	0.01	0.11					
Average				0.18	Average				0.69
L. saepiaria 2/15/17, *B. prodigiosus* 3/30/17					*L. saepiaria* 2/5/17, *B. vulgaris* & *B. coli* 4/2/17				
91	8.80	8.75	0.05	0.52	131*	10.07	10.01	0.06	0.60
92*	9.35	9.27	0.08	0.85	132	8.51	8.46	0.05	0.59
93	9.74	9.63	0.11	1.13	133*	10.39	10.36	0.03	0.30
94*	8.95	8.68	0.27	3.05	134	9.51	9.37	0.14	1.47
96	8.51	8.42	0.09	0.99	135	8.26	8.15	0.11	1.36
97	9.13	9.07	0.06	0.66	136	9.33	9.21	0.12	1.29
100*	8.40	8.35	0.05	0.59	137	10.67	10.44	0.23	2.16
					138	8.79	8.75	0.04	0.45
					140*	10.04	10.02	0.02	0.20
Average				1.11	Average				0.95

* No bacteria present after incubation.
† *Bacterium mycoides* present after incubation.
‡ *Bacillus vulgatus* present after incubation.

TABLE XIV (Continued)

I	II	III	IV	V
Culture bottle	Weight of sawdust before decay (gms.)	Weight of sawdust after decay (gms.)	Loss in weight due to decay (gms.)	Loss due to decay (per cent)
L. saepiaria 2/5/17, *Azotobacter chroococcum* 4/2/17				
141*	9.58	9.47	0.11	1.15
142	8.67	8.61	0.06	0.69
143	9.82	9.73	0.09	0.92
144*	8.09	8.02	0.07	0.86
145	9.37	9.35	0.02	0.21
146*	8.44	8.41	0.03	0.35
147	8.76	8.67	0.09	1.03
148	10.35	10.16	0.19	1.86
149	8.43	8.43	0.00	0.00
Average	......	......	......	0.78
Polystictus versicolor 2/4/17				
151	11.75	11.75	0.00	0.00
152	8.02	8.02	0.00	0.00
153	11.15	11.15	0.00	0.00
155	9.18	9.18	0.00	0.00
156	10.25	10.25	0.00	0.00
157	7.74	7.73	0.01	0.13
158	9.11	9.11	0.00	0.00
161	10.05	10.05	0.00	0.00
162	10.31	10.29	0.02	0.19
Average	......	......	......	0.04
P. versicolor 2/4/17, *B. prodigiosus* 3/30/17				
191*	8.63	8.61	0.02	0.23
192	9.01	8.98	0.03	0.33
193	8.59	8.57	0.02	0.23
194	8.86	8.79	0.07	0.81
195	10.95	10.81	0.14	1.28
196*	8.59	8.49	0.10	1.24
197	8.86	8.77	0.09	1.01
198	9.35	9.35	0.00	0.00
199*	10.02	9.66	0.36	3.53
Average	......	......	......	0.61

I	II	III	IV	V
Culture bottle	Weight of sawdust before decay (gms.)	Weight of sawdust after decay (gms.)	Loss in weight due to decay (gms.)	Loss due to decay (per cent)
P. versicolor 2/4/17, *Bact. mycoides* 3/30/17				
172*	10.55	10.54	0.01	0.10
173*	9.40	9.25	0.15	1.60
174	10.08	9.95	0.13	1.28
175	10.15	9.99	0.16	1.58
176	10.24	10.23	0.01	0.10
177	9.18	9.14	0.04	0.44
178	8.07	7.98	0.09	1.11
179	10.11	10.11	0.00	0.00
180*	8.54	8.53	0.01	0.12
Average	......	......	......	0.70
P. versicolor 2/4/17, *B. prodigiosus* & *Bact. mycoides* 3/31/17				
181	9.12	9.05	0.07	0.77
182*	10.34	10.31	0.03	0.28
183	9.88	9.88	0.00	0.00
184	9.27	9.14	0.13	1.40
185	10.11	10.09	0.02	0.20
186*	10.49	10.33	0.16	1.52
187	9.39	9.31	0.08	0.85
188	9.30	9.24	0.06	0.65
189*	9.16	9.10	0.06	0.65
190	10.36	10.33	0.03	0.29
Average	......	......	......	0.66
P. versicolor 2/4/17, *B. vulgaris* & *B. coli* 4/2/17				
201	9.28	9.17	0.11	1.19
202*	9.55	9.46	0.09	0.94
203*	9.31	9.11	0.20	2.14
204	9.90	9.73	0.17	1.72
205*	9.70	9.69	0.01	0.10
206	10.00	9.94	0.06	0.60
207	10.43	10.25	0.18	1.72
208	8.93	8.81	0.12	1.34
210	9.53	9.52	0.01	0.11
Average	......	......	......	0.98

* No bacteria present after incubation.

TABLE XIV (Continued)

I	II	III	IV	V	I	II	III	IV	V
P. versicolor 2/4/17, *Azotobacter chroococcum* 4/2/17					*P. versicolor* 2/4/17, *B. vulgatus* & *Bact. mycoides* 4/2/17				
211*	9.12	9.12	0.00	0.00	891	8.26	8.26	0.00	0.00
212*	10.48	10.41	0.07	0.67	892	10.86	10.69	0.17	1.59
213	8.46	8.41	0.05	0.59	893	9.03	8.94	0.09	1.00
214*	9.78	9.77	0.01	0.11	894	8.73	8.63	0.10	1.14
215	8.57	8.43	0.14	1.63	895†‡	9.36	9.20	0.16	1.71
216	8.59	8.56	0.03	0.35	896	10.59	10.42	0.17	1.61
217	9.25	9.12	0.13	1.40	897†‡	9.43	9.40	0.03	0.32
218	9.25	9.20	0.05	0.54	898	9.27	9.13	0.14	1.51
219	9.52	9.49	0.03	0.37	899	8.92	8.88	0.04	0.45
220	9.70	9.70	0.00	0.00	900†‡	9.11	9.08	0.03	0.33
Average	......	......	......	0.57	Average	......	......	......	0.96

TABLE XV (Series B)

THE EFFECT OF BACTERIA ON THE RATE OF DECAY INDUCED BY FOMES PINICOLA, POLYSTICTUS VERSICOLOR, AND LENZITES SAEPIARIA ON WHITE ASH

Control, error due to weighing ±0.01%					*F. pinicola* 2/16/17, *L. saepiaria* 3/30/17				
1071	9.00	9.00	0.00	0.00	681	6.06	5.78	0.28	4.61
1072	6.17	6.17	0.00	0.00	682	5.83	5.57	0.26	4.46
1073	6.29	6.28	0.01	0.15	684	6.29	5.81	0.48	7.13
1074	5.80	5.80	0.00	0.00	685	5.58	5.10	0.48	8.59
1075	7.75	7.75	0.00	0.00	686	7.63	7.45	0.18	2.36
1076	9.35	9.35	0.00	0.00	687	6.35	5.97	0.38	6.00
1077	9.01	9.01	0.00	0.00	688	7.41	7.15	0.26	3.50
1078	9.87	9.87	0.00	0.00	689	5.94	5.45	0.49	8.25
1079	8.55	8.55	0.00	0.00	690	7.60	7.56	0.04	0.53
1080	10.24	10.24	0.00	0.00	......	......	......	......	......
Average	......	......	......	0.01	Average	......	......	......	5.05
Fomes pinicola 2/16/17					*F. pinicola* 2/16/17, *L. saepiaria* & *P. versicolor* 3/30/17				
661	6.17	5.93	0.24	3.89	691	6.76	4.78	1.98	28.29
663	6.50	5.96	0.54	6.79	692	5.53	3.75	1.78	32.15
664	5.74	5.54	0.20	3.49	693	6.52	4.40	2.12	33.52
665	6.70	6.55	0.15	2.24	694	6.31	4.64	1.67	31.41
666	6.04	5.77	0.27	4.47	696	6.07	4.10	1.97	32.46
667	7.08	7.02	0.06	0.85	698	5.67	3.70	1.97	34.75
668	6.26	5.98	0.28	4.47	700	6.61	4.76	1.85	28.40
669	6.77	6.61	0.16	2.36	......	......	......	......	......
670	5.89	5.57	0.32	5.45	......	......	......	......	......
Average	......	......	......	4.89	Average	......	......	......	31.54
F. pinicola 2/16/17, *P. versicolor* 3/30/17					*F. pinicola* 2/16/17, *B. prodigiosus* 3/30/17				
671	6.15	5.49	0.66	10.73	701*	7.35	7.15	0.20	2.72
672	7.54	6.91	0.63	8.35	702	6.74	6.52	0.22	3.32
673	6.71	4.26	1.45	21.57	704	6.77	6.47	0.30	4.43
674	5.97	4.25	1.72	28.85	705	6.53	6.33	0.20	3.06
675	6.80	5.14	1.66	24.42	706	6.07	5.95	0.12	1.98
676	5.74	4.33	1.41	24.60	707*	7.25	7.15	0.10	1.38
677	6.15	5.97	0.18	2.93	708	6.07	5.33	0.74	12.18
678	6.79	5.51	1.28	18.88	709	6.67	6.28	0.39	5.84
679	5.92	4.87	1.05	17.75	710*	6.64	6.29	0.35	5.27
680	6.84	4.56	1.28	18.71	......	......	......	......	......
Average	......	......	......	17.68	Average	......	......	......	4.46

* No bacteria present after incubation.

† *Bacterium mycoides* present after incubation.

‡ *Bacillus vulgatus* present after incubation.

TABLE XV (Continued)

I	II	III	IV	V	I	II	III	IV	V
Culture bottle	Weight of sawdust before decay (gms.)	Weight of sawdust after decay (gms.)	Loss in weight due to decay (gms.)	Loss due to decay (per cent)	Culture bottle	Weight of sawdust before decay (gms.)	Weight of sawdust after decay (gms.)	Loss in weight due to decay (gms.)	Loss due to decay (per cent)
F. pinicola 2/16/17, *Bact. mycoides* 3/31/17					*L. saepiaria* 2/5/17, *B. prodigiosus* 3/30/17				
711*	5.86	5.17	0.69	11.75	751	6.95	4.58	2.37	34.10
712	5.80	5.65	0.15	2.59	752*	6.63	4.12	2.51	37.88
713*	6.63	7.50	0.13	1.96	753	6.76	4.87	1.89	27.91
714	6.77	6.44	0.33	4.87	754	6.94	4.34	2.60	37.46
716	6.12	6.04	0.08	1.31	755	6.25	4.53	1.72	27.52
717	7.25	7.08	0.17	2.34	756*	6.98	4.99	1.99	24.98
718*	5.92	5.89	0.03	0.51	757*	7.93	5.12	2.81	35.45
719	6.15	5.79	0.36	5.85	759	7.41	5.83	1.58	21.30
720	7.56	6.99	0.57	7.53	760	7.82	5.00	2.82	36.01
Average	......	......	......	4.30	Average	......	......	......	31.40
F. pinicola 2/16/17, *B. prodigiosus* & *Bact. mycoides* 3/31/17					*L. saepiaria* 2/5/17, *Bact. mycoides* 3/31/17				
721	7.09	6.72	0.37	5.22	761	7.77	5.84	1.93	24.85
723	7.14	6.37	0.77	10.78	763	9.10	5.58	3.52	38.72
725	7.53	7.02	0.51	6.77	764	7.93	4.92	3.01	37.98
726*	7.18	6.72	0.46	5.61	765*	7.75	4.95	2.80	36.12
727*	6.95	6.39	0.56	8.06	766	8.12	5.23	2.89	35.61
728*	6.18	6.07	0.11	1.76	768*	8.37	5.82	2.55	30.50
729	6.66	6.60	0.06	0.90	769	6.64	4.65	1.99	30.04
730	6.86	6.85	0.01	0.15	770*	7.25	4.80	2.45	33.80
Average	......	......	......	4.91	Average	......	......	......	33.74
Lenzites saepiaria 2/5/17					*L. saepiaria* 2/5/17, *B. prodigiosus* & *Bact. mycoides* 3/31/17				
742	5.71	3.82	1.89	33.10	771*	6.63	4.63	2.00	30.19
743	7.84	5.16	2.68	34.15	772	7.37	5.49	1.88	25.50
745	6.77	4.86	1.91	28.65	773	7.88	5.49	2.39	30.32
746	6.46	4.56	1.90	29.40	774*	7.88	5.40	2.48	31.50
748	6.54	4.57	1.97	30.15	775	6.19	4.07	2.12	34.30
750	6.31	4.09	2.22	35.01	776	6.47	4.78	1.69	26.13
					777	6.87	4.44	2.43	35.40
					780*	7.10	4.24	2.86	40.25
Average	......	......	......	31.74	Average	......	......	......	31.62

* No bacteria present after incubation.

TABLE XV (Continued)

I	II	III	IV	V
L. saepiaria 2/5/17, *B. vulgatus* & *Bact. mycoides* 4/2/17				
971‡	12.34	7.91	4.43	35.90
972‡	9.72	6.44	3.28	33.75
973	8.01	5.10	2.91	36.15
974	8.61	5.67	2.94	34.10
975	7.64	5.01	2.63	34.45
976*	7.64	5.18	2.46	32.20
977	8.20	5.41	2.79	34.01
978	8.48	5.60	2.88	34.00
979	8.08	5.61	2.47	30.55
980	8.43	5.71	2.72	32.23
Average	......	....	......	33.73
L. saepiaria 2/5/17, *B. vulgaris* & *B. coli* 4/2/17				
791	6.85	4.18	2.67	38.95
792	7.19	5.44	2.75	38.26
793*	6.69	4.21	2.48	37.08
794	6.52	4.04	2.48	38.00
795*	7.26	4.31	2.95	40.01
796	6.90	4.07	1.83	26.53
797	6.83	4.45	2.38	34.82
798*	6.83	4.33	2.50	36.60
799	5.56	3.91	1.65	29.68
800	5.89	3.84	2.05	34.90
Average	......	....	......	35.48
L. saepiaria 2/5/17, *Azotobacter chroococcum* 4/2/17				
801	5.68	3.25	2.43	42.80
802	5.87	3.19	2.68	45.60
803*	6.20	3.81	2.39	38.55
804*	6.09	3.60	2.49	40.95
805*	7.41	5.31	2.10	27.32
806	5.90	3.70	2.20	37.30
807	7.70	4.52	3.18	41.25
808	6.84	4.32	2.52	36.85
809	5.97	3.47	2.50	41.80
810	6.54	3.83	2.71	41.50
Average	......	....	......	39.39
Polystictus versicolor 2/5/17				
811	5.31	4.06	1.25	23.53
812	5.10	4.43	0.67	13.13
813	6.42	5.22	1.20	18.70
814	7.91	4.26	3.65	46.08
815	7.42	3.99	3.43	46.23
816	6.89	4.99	1.90	25.60
817	7.73	5.54	2.19	28.33
818	6.67	5.35	1.32	19.78
819	7.43	4.28	3.15	42.43
820	7.20	5.23	1.97	27.35
Average	......	....	......	29.11
P. versicolor 2/5/17, *B. prodigiosus* 3/30/17				
821	7.41	3.64	3.77	50.75
822	6.43	3.38	3.05	47.45
823	7.84	3.78	4.06	51.25
824*	6.85	4.64	2.21	32.30
825	7.38	3.48	3.90	52.75
826*	7.46	3.71	3.75	50.20
827*	6.57	3.16	3.41	51.80
829	6.41	3.40	3.01	46.90
830	6.49	3.20	3.29	50.75
......	....	....	......	....
Average	......	....	......	48.24
P. versicolor 2/5/17, *Bact. mycoides* 3/31/17				
831	7.02	5.01	2.01	28.65
832	6.72	3.20	3.52	53.20
833	7.76	4.04	3.72	48.90
834*	7.16	4.01	3.15	41.60
835	7.53	3.91	3.62	46.75
836*	5.99	3.16	2.83	47.30
837	7.27	3.98	3.29	45.25
838*	5.93	2.98	2.95	49.76
839	7.75	4.09	3.66	47.08
840	6.05	3.06	2.99	49.48
Average	......	....	......	45.70
P. versicolor 2/5/17, *B. prodigiosus* & *Bact. mycoides* 3/31/17				
841	7.52	3.99	3.53	47.00
842*	6.71	3.82	2.89	43.03
843	7.81	4.10	3.71	47.50
844	8.19	4.38	3.81	46.60
845	7.95	3.46	4.49	56.44
846*	6.97	3.49	3.48	49.95
847	7.47	3.84	3.63	48.70
848†	7.60	3.60	4.00	52.70
849	7.41	4.07	3.34	45.01
850	7.85	3.78	4.07	51.80
Average	......	....	......	48.87
P. versicolor 2/5/17, *B. vulgaris* & *B. coli* 4/2/17				
861	7.18	3.35	3.83	53.40
862	7.85	3.83	4.02	51.20
863	7.16	3.96	3.20	44.70
864*	6.41	3.55	2.86	44.60
865	8.45	4.22	4.23	50.10
867*	6.79	3.54	3.25	47.95
868*	7.52	3.78	3.74	49.70
869	7.58	3.82	3.76	49.60
870	7.02	3.63	3.39	48.30
......	....	....	......	....
Average	......	....	......	48.84

* No bacteria present after incubation.

† *Bacterium mycoides* present after incubation.

‡ *Bacillus vulgatus* present after incubation.

TABLE XV (Continued)

I	II	III	IV	V	I	II	III	IV	V
Culture bottle	Weight of sawdust before decay (gms.)	Weight of sawdust after decay (gms.)	Loss in weight due to decay (gms.)	Loss due to decay (per cent)	Culture bottle	Weight of sawdust before decay (gms.)	Weight of sawdust after decay (gms.)	Loss in weight due to decay (gms.)	Loss due to decay (per cent)
P. versicolor 2/5/17, *Azotobacter chroococcum* 4/2/17					*P. versicolor* 2/5/17, *B. vulgatus* & *Bact. mycoides* 3/31/17				
871	7.03	3.39	3.64	51.75	982	8.54	4.37	4.17	48.75
872	6.59	3.23	3.36	51.10	983	7.44	3.81	3.63	48.80
873	5.59	3.02	2.57	46.00	984	8.74	4.36	4.38	50.10
874	6.33	3.37	2.96	46.75	985	8.03	3.94	4.09	50.80
875*	5.70	2.74	2.96	51.90	986*	7.63	4.03	3.60	47.15
876*	5.80	3.94	1.86	32.00	987	8.28	3.81	4.47	53.90
877	6.29	3.12	3.17	50.45	988*	7.64	5.42	2.22	29.10
878*	6.59	3.13	3.46	52.50	......	......	......	......	......
879	7.07	3.90	3.17	44.80	......	......	......	......	......
880	6.50	3.33	3.17	48.75	......	......	......	......	......
Average	......	......	......	47.60	Average	......	......	......	46.94

TABLE XVI (Series C)

THE EFFECT OF BACTERIA ON THE RATE OF DECAY INDUCED BY FOMES PINICOLA, POLYSTICTUS VERSICOLOR, AND LENZITES SAEPIARIA ON WESTERN HEMLOCK

Control, error due to weighing ±0.02%					*F. pinicola* 2/16/17, *P. versicolor* 3/29/17				
1051	9.37	9.37	0.00	0.00	235	7.78	7.26	0.52	6.68
1052	8.53	8.53	0.00	0.00	236	6.10	5.95	0.15	2.46
1053	9.11	9.11	0.00	0.00	237	6.25	6.15	0.10	1.60
1054	8.60	8.60	0.00	0.00	239	7.31	7.08	0.23	3.15
1055	7.32	7.32	0.00	0.00	240	6.75	8.63	0.12	1.78
1056	7.47	7.46	0.01	0.13	241	6.69	6.58	0.11	1.64
1057	9.23	9.23	0.00	0.00	245	6.75	6.38	0.37	5.49
1058	6.04	6.04	0.00	0.00	......	......	......	......	......
1059	8.53	8.53	0.00	0.00	......	......	......	......	......
1060	9.16	9.15	0.00	0.11	......	......	......	......	......
Average	......	......	......	0.02	Average	......	......	......	3.26
Fomes pinicola 2/16/17					*F. pinicola* 2/26/17, *L. saepiaria* 3/30/17				
222	7.43	7.25	0.18	2.48	246	7.52	6.46	1.06	14.62
223	4.78	5.43	0.35	7.32	247	7.88	6.29	1.59	21.90
224	7.27	7.19	0.08	1.67	248	7.45	6.67	0.78	10.48
225	6.06	5.92	0.14	2.31	249	7.25	7.12	0.13	1.79
226	7.28	6.96	0.32	4.40	250	7.48	6.73	0.75	10.05
227	7.55	7.41	0.14	1.85	251	9.60	8.63	0.97	10.10
......	......	......	......	......	252	7.48	7.30	0.18	2.42
......	......	......	......	......	253	7.18	7.10	0.08	1.11
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
Average	......	......	......	3.34	Average	......	......	......	10.31

* No bacteria present after incubation.

TABLE XVI (Continued)

I	II	III	IV	V	I	II	III	IV	V
F. pinicola 2/16/17, *P. versicolor* & *L. saepiaria* 3/30/17					*Lenzites saepiaria* 2/5/17				
255	7.47	6.86	0.61	8.16	301	6.96	6.33	1.63	23.40
256	6.97	6.22	0.75	10.75	302	6.25	5.58	0.67	10.73
257	8.01	7.06	0.95	11.87	303	7.22	5.81	1.41	19.51
258	7.02	6.29	0.73	10.40	304	7.94	6.06	1.88	23.70
259	7.58	6.67	0.91	12.00	305	7.52	5.93	1.59	21.12
262	8.00	7.07	0.93	11.62	306	6.66	5.53	1.13	16.95
263	7.66	6.93	0.73	9.53	307	7.17	5.56	1.61	22.41
......	......	......	......	......	308	6.87	5.40	1.47	21.40
......	......	......	......	......	309	7.29	5.85	1.44	19.70
......	......	......	......	......	310	6.45	5.19	1.26	19.52
Average	......	......	......	10.72	Average	......	......	......	19.84
F. pinicola 2/16/17, *B. prodigiosus* 3/30/17					*L. saepiaria* 2/5/17, *B. prodigiosus* 3/30/17				
265*	6.42	6.09	0.33	5.15	311*	7.22	5.40	1.82	25.20
266	7.13	6.83	0.30	4.21	312	7.05	5.02	2.03	28.80
267	9.03	8.96	0.07	0.77	313	8.46	6.32	2.14	25.22
269	6.55	6.27	0.28	4.28	314	7.87	5.90	1.97	25.02
270*	6.84	6.75	0.09	1.32	315*	7.62	5.80	1.82	23.84
271*	9.02	8.32	0.70	7.77	316	6.42	4.86	1.56	24.30
272	7.61	7.11	0.50	6.56	317*	7.05	5.33	1.72	24.40
273	7.48	6.90	0.58	7.76	318	6.85	5.03	1.82	26.58
......	......	......	......	......	319	7.84	6.95	0.89	11.36
......	......	......	......	......	320	7.64	5.69	1.95	24.90
Average	......	......	......	4.72	Average	......	......	......	23.96
F. pinicola 2/16/17, *Bact. mycoides* 3/30/17					*L. saepiaria* 2/5/17, *Bact. mycoides* 3/31/17				
274	6.24	6.13	0.11	1.76	321	7.78	5.50	2.28	28.30
275†	7.59	7.31	0.28	3.69	322	7.53	5.55	1.98	26.31
276	7.37	7.07	0.30	4.07	323	6.94	5.38	1.56	22.52
277	6.98	6.60	0.38	5.44	324	7.32	5.41	1.91	26.10
278	7.32	6.91	0.41	5.60	325†	6.54	4.78	1.76	26.90
279	9.10	8.79	0.31	3.41	326	6.10	4.37	1.73	28.34
280†	7.48	7.10	0.38	5.09	328	6.67	5.15	1.52	22.80
281†	7.27	6.92	0.35	4.81	329†	7.36	5.45	1.91	25.92
282	8.32	7.92	0.40	4.81	330†	6.44	4.73	1.71	26.60
......	......	......	......	......	......	......	......	......	......
Average	......	......	......	4.29	Average	......	......	......	25.98
F. pinicola 2/16/17, *B. prodigiosus* & *Bact. mycoides* 3/31/17					*L. saepiaria* 2/5/17, *B. prodigiosus* & *Bact. mycoides* 3/31/17				
283	8.00	7.90	0.10	1.25	331	6.86	5.40	1.46	21.28
284	7.53	7.03	0.50	6.64	332†	7.43	5.72	1.71	23.00
285	7.18	6.89	0.29	4.04	333	6.49	4.89	1.60	24.66
286†	6.83	6.55	0.28	4.10	334	7.34	5.52	1.82	24.78
287†	7.95	7.54	0.41	5.15	335	8.16	6.01	2.15	26.30
288	7.10	6.75	0.35	4.92	336	7.12	5.30	1.82	25.56
289	6.45	6.17	0.28	4.45	337†	7.76	5.65	2.11	27.13
290†	7.39	7.03	0.36	4.88	338	8.32	6.28	2.04	24.51
291	7.60	7.31	0.29	3.82	339	7.34	6.05	1.29	17.58
......	......	......	......	......	340†	7.82	5.60	1.22	15.61
Average	......	......	......	4.36	Average	......	......	......	23.04

* No bacteria present after incubation.
† *Bacterium mycoides* present after incubation.

TABLE XVI (Continued)

I	II	III	IV	V
Culture bottle	Weight of sawdust before decay (gms.)	Weight of sawdust after decay (gms.)	Loss in weight due to decay (gms.)	Loss due to decay (per cent)
L. saepiaria 2/5/17, *B. vulgaris* & *B. coli* 4/2/17				
351	6.97	5.11	1.86	26.70
352	7.31	5.39	1.92	26.28
353	7.66	5.69	1.97	25.80
354	7.19	5.23	1.96	27.28
355*	6.90	5.35	1.55	22.50
356	6.95	5.25	1.70	24.48
357*	7.08	5.35	1.73	24.42
358	7.95	5.87	2.08	26.18
359*	7.55	5.51	2.04	27.03
360	6.96	5.33	1.63	23.40
Average	......	......	......	25.41
L. saepiaria 2/5/17, *Azotobacter chroococcum* 4/2/17				
361	7.54	5.62	1.92	25.48
362	6.36	5.49	1.87	29.45
363	7.56	5.53	2.03	26.86
364	6.52	5.83	1.69	25.91
365	7.89	5.65	2.24	28.40
366*	7.77	5.69	2.08	26.76
367	8.97	6.61	2.36	26.26
368	7.33	5.27	2.06	28.10
369*	7.08	5.46	1.62	22.88
370*	7.23	5.26	1.97	27.26
Average	......	......	......	26.74
L. saepiaria 2/5/17, *B. vulgatus* & *Bact. mycoides* 4/2/17				
911	6.82	5.19	1.63	23.92
912*	7.14	5.38	1.76	24.70
913	9.08	7.04	2.04	22.48
914*	7.15	5.17	1.98	27.72
915	7.10	5.38	1.72	24.25
916	7.87	5.84	2.03	25.85
917*	7.64	5.91	1.73	22.64
918	7.58	5.21	2.37	31.32
919	7.79	5.75	2.04	26.23
920	7.86	5.78	2.08	26.45
Average	......	......	......	25.55
Polystictus versicolor 2/5/17				
371	7.19	7.10	0.09	1.25
372	6.90	6.79	0.11	1.59
373	7.82	7.67	0.15	1.92
374	7.05	7.03	0.02	0.28
375	7.29	7.16	0.13	1.78
376	9.92	9.81	0.11	1.11
377	8.53	8.40	0.13	1.52
379	8.62	8.54	0.08	0.93
380	9.17	8.99	0.18	1.96
Average	......	......	......	1.37
P. versicolor 2/5/17, *B. prodigiosus* 3/30/17				
381	8.23	7.84	0.39	4.24
382	7.43	7.24	0.19	2.55
384	6.76	6.45	0.31	4.59
385*	8.19	7.94	0.25	3.06
386	7.01	6.59	0.42	6.00
387*	9.63	9.18	0.45	4.67
388	7.66	7.25	0.41	5.35
389*	8.40	7.98	0.42	5.00
Average	......	......	......	4.43
P. versicolor 2/5/17, *Bact. mycoides* 3/30/17				
392	8.78	7.38	0.40	4.56
393†	8.29	8.05	0.24	3.18
394	7.22	6.87	0.35	4.85
395†	6.62	6.46	0.16	2.42
397	7.60	7.17	0.43	5.66
398	6.39	6.26	0.13	2.04
399	7.53	7.36	0.17	2.26
400†	7.39	7.22	0.17	2.30
Average	......	......	......	3.41

* No bacteria present after incubation.

† *Bacterium mycoides* present after incubation.

TABLE XVI (Continued)

I	II	III	IV	V	I	II	III	IV	V
P. versicolor 2/5/17, *B. prodigiosus* & *Bact. mycoides* 3/30/17					*P. versicolor* 2/5/17, *Azotobacter chroococcum* 4/2/17				
401†	8.29	8.04	0.25	3.02	431	7.43	7.28	0.15	2.02
402	8.19	8.05	0.14	1.71	432	6.41	6.32	0.09	1.40
403	7.10	6.90	0.20	2.82	433	8.28	8.13	0.15	1.81
404	8.65	8.30	0.35	4.05	435	7.38	7.19	0.19	2.57
405	6.27	6.03	0.24	3.82	436*	7.57	7.22	0.35	4.62
406	7.13	6.97	0.16	2.24	437*	7.09	6.89	0.20	2.53
407	7.75	7.56	0.19	2.45	438	7.68	7.60	0.08	1.04
409†	7.14	6.95	0.19	2.66	439*	8.46	8.22	0.24	2.83
410†	8.86	8.68	0.18	2.03	440	8.35	8.11	0.24	2.87
Average	......	......	......	2.47	Average	......	......	......	2.41
P. versicolor 2/5/17, *B. vulgaris* & *B. coli* 4/2/17					*P. versicolor* 2/5/17, *B. vulgatus* & *Bact. mycoides* 4/2/17				
421	7.64	7.49	0.15	1.96	921	7.56	7.34	0.22	2.91
422*	8.09	7.81	0.28	3.46	922†	6.76	6.60	0.16	2.37
423*	9.84	7.36	0.48	4.48	923	6.79	6.66	0.13	1.92
424	8.02	7.68	0.34	4.23	924†	7.11	6.91	0.20	2.81
425	7.63	7.44	0.19	2.49	925	6.98	6.77	0.21	3.01
426*	6.47	6.36	0.11	1.70	926	7.18	7.02	0.16	2.23
427	7.30	7.15	0.15	2.06	927	7.00	6.75	0.25	3.58
428	7.45	7.25	0.20	2.68	928	6.46	6.25	0.21	3.24
429	7.33	6.97	0.36	4.90	929†	7.36	7.11	0.25	3.39
Average	......	......	......	3.15	Average	......	......	......	2.83

TABLE XVII (Series D)

THE EFFECT OF BACTERIA ON THE RATE OF DECAY INDUCED BY FOMES PINICOLA, POLYSTICTUS VERSICOLOR, AND LENZITES SAEPIARIA ON DOUGLAS FIR

Control, error due to weighing ±0.03%					*F. pinicola* 2/16/17, *P. versicolor* 3/29/17				
1061	7.29	7.29	0.00	0.00	451	8.25	7.82	0.43	5.21
1062	7.32	7.32	0.00	0.00	452	7.24	7.15	0.09	1.24
1063	7.09	7.09	0.00	0.00	453	7.08	6.92	0.16	2.26
1064	8.86	8.86	0.00	0.00	454	7.56	7.18	0.38	5.01
1065	9.08	9.07	0.01	0.11	455	7.65	7.63	0.02	0.26
1066	9.18	9.18	0.00	0.00	456	7.60	7.34	0.26	3.42
1067	8.07	8.06	0.01	0.12	457	6.99	6.94	0.05	0.71
1068	8.46	8.46	0.00	0.00	458	7.73	7.40	0.33	4.27
1069	7.21	7.21	0.00	0.00	459	7.58	7.15	0.43	5.68
1070	9.28	9.29	0.01	0.11	......	......	......	......	......
Average	......	......	......	0.03	Average	......	......	......	3.12
Fomes pinicola 2/16/17					*F. pinicola* 2/16/17, *L. saepiaria* 3/30/17				
441	7.62	7.11	0.51	6.68	461	8.32	8.05	0.27	3.24
442	8.55	8.00	0.55	5.75	463	6.43	6.35	0.08	1.24
443	7.25	7.18	0.07	0.96	464	8.02	7.77	0.25	3.12
444	7.72	7.65	0.07	0.91	465	7.62	7.50	0.12	1.58
445	8.25	7.75	0.50	6.05	466	7.39	7.04	0.35	4.75
446	7.57	7.45	0.12	1.58	467	7.78	7.56	0.22	2.83
447	8.04	7.73	0.31	3.86	469	7.06	6.67	0.39	5.50
448	8.01	7.83	0.18	2.25	470	8.16	7.76	0.40	4.90
449	8.04	7.94	0.10	1.24	......	......	......	......	......
450	6.84	6.81	0.03	0.44	......	......	......	......	......
Average	......	......	......	2.97	Average	......	......	......	3.02

* No bacteria present after incubation.

† *Bacterium mycoides* present after incubation.

TABLE XVII (Continued)

I	II	III	IV	V	I	II	III	IV	V
Culture bottle	Weight of sawdust before decay (gms.)	Weight of sawdust after decay (gms.)	Loss in weight due to decay (gms.)	Loss due to decay (per cent)	Culture bottle	Weight of sawdust before decay (gms.)	Weight of sawdust after decay (gms.)	Loss in weight due to decay (gms.)	Loss due to decay (per cent)
F. pinicola 2/16/17, *L. saepiaria* & *P. versicolor* 3/30/17					*F. pinicola* 2/16/17, *B. prodigiosus* & *Bact. mycoides* 3/31/17				
471	8.41	7.81	0.60	7.13	501	8.84	8.40	0.44	4.98
472	8.62	7.78	0.84	9.75	502	8.52	8.18	0.34	3.99
473	8.18	7.55	0.63	7.71	503	8.69	8.47	0.22	2.53
474	8.23	7.64	0.59	7.18	504	9.22	8.87	0.35	3.69
475	9.10	8.59	0.51	5.61	505	8.98	8.56	0.42	4.67
476	7.42	7.00	0.42	5.66	506†	8.21	7.71	0.50	6.09
478	7.45	6.88	0.57	7.65	507	7.77	7.31	0.46	6.28
479	8.74	8.18	0.56	6.43	508†	7.89	7.67	0.22	2.79
480	8.45	7.56	0.89	10.52	509†	7.89	7.72	0.17	2.16
....	......	......	......	......	510	9.86	9.40	0.46	4.65
Average				7.52	Average				4.18
Fomes pinicola 2/16/17, *B. prodigiosus* 3/30/17					*Lenzites saepiaria* 2/5/17				
481	9.51	8.89	0.62	6.52	521	7.87	6.96	0.91	11.56
482	9.91	9.51	0.40	4.04	522	9.49	8.12	1.37	14.45
483	10.36	9.87	0.49	4.74	523	8.39	7.22	1.17	13.98
484	9.31	8.65	0.66	7.08	524	7.56	6.65	0.91	12.01
485*	7.37	7.19	0.18	2.46	525	7.67	6.60	1.07	13.95
486	9.54	8.92	0.62	6.50	526	7.91	6.66	1.25	15.80
487*	8.83	8.36	0.47	5.32	528	7.61	6.57	1.04	13.65
488	8.35	8.01	0.34	4.07	529	9.38	8.12	1.26	13.42
489*	7.45	7.20	0.25	3.36	530	9.16	7.69	1.47	16.02
490	8.25	7.85	0.35	4.24	....	......	......	......	......
Average				4.83	Average				14.98
F. pinicola 2/16/17, *Bact. mycoides* 3/31/17					*L. saepiaria* 2/5/17, *B. prodigiosus* 3/31/17				
491	8.48	8.03	0.45	5.31	531	7.81	6.63	1.18	15.09
492	8.66	8.23	0.43	4.96	532*	8.67	7.36	1.31	15.13
493*	7.86	7.62	0.24	3.05	533	6.73	5.71	1.02	15.18
494	10.72	10.27	0.45	4.19	534*	8.01	6.54	1.47	18.38
495	7.63	7.45	0.18	2.36	536	7.43	6.21	1.22	16.42
496	9.26	8.71	0.55	5.92	537	7.51	6.17	1.34	17.83
497*	7.04	6.78	0.26	3.70	538*	8.58	7.00	1.58	18.45
498	10.16	9.84	0.32	3.14	539	7.44	5.98	1.46	19.61
499	7.65	7.42	0.23	3.01	540	9.53	8.15	1.38	14.47
500*	8.26	7.85	0.41	4.96	....	......	......	......	......
Average				4.06	Average				16.39

* No bacteria present after incubation.

† *Bacterium mycoides* present after incubation.

TABLE XVII (Continued)

I	II	III	IV	V
L. saepiaria 2/5/17, *Bact. mycoides* 3/31/17				
541	8.70	7.35	1.35	15.51
542	8.31	6.89	1.42	17.09
543*	7.82	6.50	1.32	16.89
544*	7.79	6.62	1.17	15.01
545	8.59	7.03	1.56	18.17
546	6.87	5.64	1.23	17.89
547	8.01	6.83	1.18	14.73
548	9.72	8.32	1.40	14.41
549*	6.62	5.72	0.90	13.59
550	7.39	6.52	0.87	11.78
Average	......	......	......	15.51
L. saepiaria 2/5/17, *B. prodigiosus* & *Bact. mycoides* 3/31/17				
551*	8.41	6.96	1.45	17.25
552	7.53	6.35	1.18	15.65
553	8.84	7.75	1.09	14.08
554	7.97	6.66	1.31	16.40
555	7.45	6.53	0.92	12.35
556*	9.28	7.89	1.39	14.99
557	9.00	7.67	1.33	14.78
559	7.28	6.37	0.91	12.51
560†	7.89	6.81	1.09	13.71
......	......	......	......	......
Average	......	......	......	14.75
L. saepiaria 2/5/17, *B. vulgaris* & *B. coli* 3/31/17				
570	8.47	7.49	0.98	11.55
573	6.25	5.38	0.87	13.92
574*	7.56	6.46	1.10	14.56
575	9.09	7.52	1.57	17.28
576*	7.04	6.16	0.88	12.50
577*	9.23	8.00	1.23	13.34
578	8.77	7.18	1.59	18.11
......	......	......	......	......
......	......	......	......	......
......	......	......	......	......
Average	......	......	......	14.47
L. saepiaria 2/5/17, *Azotobacter chroococcum* 4/2/17				
580	8.30	7.16	1.14	13.75
581	7.22	6.11	1.11	15.38
586*	7.26	6.10	1.16	15.98
587*	9.37	8.86	0.51	5.09
588	8.31	7.11	1.20	14.45
589*.	6.96	5.88	1.08	15.52
590	7.13	6.08	1.05	14.72
......	......	......	......	......
......	......	......	......	......
......	......	......	......	......
Average	......	......	......	13.55

I	II	III	IV	V
L. saepiaria 2/5/17, *B. vulgatus* & *Bact. mycoides* 4/2/17				
941*	8.84	7.67	1.17	13.52
942*	8.40	7.21	1.19	14.19
945	7.73	6.61	1.12	14.49
946	8.63	7.31	1.32	15.30
947*	8.50	8.33	0.17	2.00
948	6.76	5.75	1.01	14.93
949	6.98	6.03	0.95	13.60
......	......	......	......	......
......	......	......	......	......
......	......	......	......	......
Average	......	......	......	12.57
Polystictus versicolor 2/5/17				
592	8.69	8.68	0.01	0.12
593	8.64	8.63	0.01	0.12
599	8.75	8.73	0.02	0.23
600	8.69	8.67	0.02	0.23
603	8.17	8.16	0.01	0.12
604	9.26	9.24	0.02	0.22
605	8.80	8.79	0.01	0.12
606	9.05	9.03	0.02	0.22
......	......	......	......	......
......	......	......	......	......
Average	......	......	......	0.17
P. versicolor 2/5/17, *B. prodigiosus* 3/30/17				
608*	7.80	7.57	0.23	2.95
609	9.61	9.23	0.38	3.96
611	7.27	7.15	0.12	1.65
612	8.13	8.01	0.12	1.47
613*	7.15	7.09	0.06	0.84
614	7.67	7.60	0.07	0.91
615	8.01	7.80	0.21	2.62
616*	7.48	7.31	0.17	2.27
617	9.27	8.96	0.31	3.34
618	8.93	8.70	0.23	2.58
Average	......	......	......	2.26
P. versicolor 2/5/17, *Bact. mycoides* 3/31/17				
619*	7.96	7.74	0.22	2.77
620*	7.45	7.33	0.12	1.61
621*	7.37	7.30	0.07	0.95
624	7.07	6.86	0.21	2.97
625	9.06	8.87	0.19	2.04
626	7.69	7.64	0.05	0.65
627	8.91	8.89	0.02	0.22
628	6.62	6.57	0.05	0.75
629	8.33	8.22	0.11	1.32
630	7.13	7.07	0.06	0.84
Average	......	......	......	1.42

*No bacteria present after incubation.

†*Bacterium mycoides* present after incubation.

TABLE XVII (Continued)

I	II	III	IV	V	I	II	III	IV	V
Culture bottle	Weight of sawdust before decay (gms.)	Weight of sawdust after decay (gms.)	Loss in weight due to decay (gms.)	Loss due to decay (per cent)	Culture bottle	Weight of sawdust before decay (gms.)	Weight of sawdust after decay (gms.)	Loss in weight due to decay (gms.)	Loss due to decay (per cent)
P. versicolor 2/5/17, *Azotobacter chroococcum* 4/2/17					*P. versicolor* 2/5/17, *B. vulgatus* & *Bact. mycoides* 3/31/17				
651	7.79	7.78	0.01	0.13	951	8.88	8.75	0.13	1.46
653*	8.18	8.02	0.16	1.96	952*	7.59	7.53	0.06	0.79
654*	8.46	8.35	0.11	1.30	954†	8.59	7.54	0.05	0.58
656	8.53	7.51	0.02	0.23	955	8.09	8.03	0.06	0.74
657*	9.95	9.75	0.20	2.01	956	7.01	6.91	0.10	1.56
659	7.09	7.07	0.02	0.28	957*	7.16	7.06	0.10	1.39
660	7.29	7.25	0.04	0.55	959	7.41	7.29	0.12	1.62
					960	7.80	7.71	0.09	1.15
Average				0.92	Average				1.16

* No bacteria present after incubation.
† *Bacterium mycoides* present after incubation.

The average results of the foregoing series are tabulated in table XVIII.

THE GROWTH OF PURE CULTURES OF BACTERIA ON SAWDUST AND THEIR EFFECT ON THE REACTION OF THE SAWDUST EXTRACT

Due to the fact that in most of the cultures bacteria were no longer found alive at the end of the period of incubation, pure cultures of the organisms were grown on sawdust in order to determine whether or not the sawdust was toxic and the effect, if any, of the bacteria on the reaction of the extract.

Equal amounts, 5.00 gms., of sawdust were placed in 125-cc. Erlenmeyer flasks and 50 cc. of distilled water were added to each. The flasks were plugged and autoclaved for one hour and subsequently inoculated with various species of bacteria. After thirty days' incubation at room temperature transfers were made from the flasks to hard potato agar, and the reaction of the wood extract determined by titrating 5 cc. of the extracts against N/20 sodium hydroxide. Red oak, western hemlock, and Douglas fir were used in this work, with *Bacillus*

TABLE XVIII

AVERAGE LOSS PER CENT IN CULTURE SERIES A, B, C AND D

Second inoculation	Average loss (per cent)											
	Series A Red oak			Series B White ash			Series C Western hemlock			Series D Douglas fir		
	Fomes pinicola	Lenzites saepiaria	Polystictus versicolor	Fomes pinicola	Lenzites saepiaria	Polystictus versicolor	Fomes pinicola	Lenzites saepiaria	Polystictus versicolor	Fomes pinicola	Lenzites saepiaria	Polystictus versicolor
Control (not inoculated)	±0.02			±0.01			±0.02			±0.03		
Fungus alone	0.10	0.18	0.04	4.89	31.74	29.11	3.34	19.34	1.37	2.97	14.98	0.17
Polystictus versicolor	0.36	......	......	17.68	......	......	2.85	......	......	3.12	......	......
Lenzites saepiaria	0.29	......	......	5.05	......	......	10.31	......	......	3.02	......	......
Polystictus versicolor & *Lenzites saepiaria*	1.24	......	......	31.54	......	......	10.72	......	......	7.52	......	......
Bacillus prodigiosus	1.79	1.11	0.61	4.46	31.40	48.24	4.72	23.96	4.43	4.83	16.39	2.26
Bacterium mycoides	2.00	0.56	0.70	4.30	33.74	45.70	4.29	25.98	3.41	4.06	15.51	1.42
Bacillus prodigiosus & *Bacterium mycoides*	1.97	0.25	0.66	4.91	31.62	48.87	4.36	23.04	2.74	4.18	14.75	......
Bacillus vulgatus & *Bacterium mycoides*	......	0.69	0.96	......	33.73	46.94	......	25.25	2.83	......	12.57	1.16
Bacillus vulgaris & *Bacillus coli*	......	0.95	0.98	......	35.48	48.84	......	25.41	3.15	......	14.47	......
Azotobacter chroococcum	......	0.78	0.57	......	39.39	47.60	......	26.74	2.41	......	13.35	0.92

coli, *B. vulgaris*, *B. prodigiosus*, and *B. vulgatus* as the organisms.

The results of the titrations, expressed in degrees of acidity, Fuller's scale, are given in table xix. All series were run in triplicate and the following results are the average of three titrations:

TABLE XIX

THE EFFECT OF PURE CULTURES OF BACTERIA ON THE REACTION OF WOOD EXTRACTS

Organism	Red oak	Western hemlock	Douglas fir
Control	13.0	2.5	3.0
Bacillus coli	13.0	2.0	3.2
Bacillus vulgaris	13.5	2.5	3.0
Bacillus prodigiosus	13.7	....	3.5
Bacillus vulgatus	13.3	....	3.3

In the case of the red oak extract the end point could not be exactly determined because of the dark color of the extract which might account for the slight variations in the titrations. It is evident therefore that these organisms do not change the titratable acidity of the wood extracts to any considerable extent, if at all.

Transfers made from the cultures at the end of thirty days' incubation to hard potato agar were negative in every case, indicating that the wood extracts were either toxic to, or lacked some of, the necessary substances for continued growth of the organisms.

Discussion of Results

SERIES A: RED OAK

The rate of decay of red oak was comparatively slow with the three fungi used. *Lenzites saepiaria* caused the most rapid loss in weight in the culture bottles. In cultures first inoculated with *Fomes pinicola* and subsequently with *Polystictus versicolor* and *Lenzites saepiaria* the rate of decay was greater than that caused by any of the fungi growing separately and indeed greater than the combined rate of the three. In all cases the rates of decay caused by the fungi alone were less than those to which cultures of bacteria were added. With *Fomes pinicola* the highest rate of decay was produced in culture bottles to which *Bacterium mycoides* was added; with *Lenzites saepiaria* the highest rate was in the culture bottles to which *Bacillus prodigiosus* was added; and with *Polystictus versicolor* in those to which *Bacillus vulgaris* and *B. coli* were added. The only bacteria found in the culture bottles at the end of the period of incubation were *Bacillus vulgatus* and *B. coli.*

SERIES B: WHITE ASH

The highest rate of decay caused by the fungi was that caused by *Lenzites saepiaria.* Cultures of *Polystictus versicolor* to which bacteria were added lost the most weight due to decay of any of the cultures of the entire series. Culture bottles first inoculated with *Fomes pinicola* and subsequently with *Lenzites saepiaria, Polystictus versicolor,* or both, lost less weight than those inoculated with *Lenzites saepiaria* or *Polystictus versicolor* alone. This is quite different from the results obtained with red oak. The addition of bacteria to cultures of *Fomes pinicola* caused no change in the rate of decay. In the case of *Polystictus versicolor* culture bottles to which bacteria were subsequently added lost more weight than did pure cultures of the fungus. The greatest loss in weight is found in cultures of *Polystictus versicolor* to which *Bacillus prodigiosus* and *Bacterium mycoides* were added. *Bacillus vulgatus* and *Bacterium mycoides* were the only bacteria found in the culture bottles at the end of the period of incubation.

SERIES C: WESTERN HEMLOCK

Lenzites saepiaria caused the highest rate of decay on western hemlock of any of the fungi used. Cultures first inoculated with *Fomes pinicola* and subsequently with *Polystictus versicolor* lost no more weight than those inoculated with *Fomes pinicola* alone. In *Fomes pinicola* cultures subsequently inoculated with *Lenzites saepiaria* the loss in weight was practically identical to that lost by pure cultures of *Lenzites saepiaria.* When *Fomes pinicola* cultures were subsequently inoculated with both *Lenzites saepiaria* and *Polystictus versicolor* the loss in weight was also practically the same as that caused by pure cultures of *Lenzites saepiaria.* Cultures of *Polystictus versicolor* to which bacteria were added, in all cases lost from two to three times more weight than was lost by pure cultures of the fungus. *Bacterium mycoides* was the only bacterium found in the culture bottles at the end of the period of incubation.

SERIES D: DOUGLAS FIR

Lenzites saepiaria caused the most rapid rate of decay of Douglas fir. The addition of bacteria to cultures of *Fomes pinicola* and *Lenzites saepiaria* caused no apparent change in the rate of decay. Cultures of *Polystictus versicolor* to which bacteria were added lost from five to ten times as much weight as did cultures of the fungus alone. *Bacterium mycoides* was the only bacterium found in the cultures at the end of the period of incubation.

SUMMARY

The experimental results obtained may be briefly summarized as follows:

1. When wood is sterilized by autoclaving it undergoes certain changes which must be considered when using wood for experimental purposes with wood-decaying fungi. Among these changes are: (a) a change in color; (b) an increase in the amount of reducing substances in the extract; (c) an increase in the acidity of the extract; (d) an increase in the hydrogen ion concentration of the extract; (e) a change in resistance towards decay.

2. Cellulose-dissolving bacteria play no important part in the decay of wood under natural conditions.

3. The results from the decaying experiments tend to indicate that the rate of decay may be materially increased by the presence of the ordinary saprophytic bacteria.

4. The influence of bacteria on fungi with reference to the rate of decay induced by the fungi varies with the different fungi on different woods.

5. Further experimentation along this line is essential.

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STUDIES IN THE PHYSIOLOGY OF THE FUNGI

VIII. Mixed Cultures

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Some consideration has been given in previous literature to the behavior of fungi in mixed cultures, but this has been sufficiently reviewed by Harder,[1] whose work along the line seems to be the most complete. His conclusions, however, are based merely upon observations on the rate of growth and color production in the medium and mycelium. The purpose of his work was to determine whether the inhibition or stimulation of growth, as the case may be, might not be the result of the depletion of the available carbohydrates in the medium or a change in the hydrogen ion concentration.

In the present work the following fungi were used: *Lenzites vialis* Pk., *Merulius pinastri* (Fr.) Burt, *Daedalea quercina* (L.) Fr., *Trametes Peckii* Kalchbr., *Pleurotus sapidus* Kalchbr., *Merulius lacrymans* (Wulf.) Fr., *Lentinus lepideus* Fr., *Daedalea confragosa* (Bolt.) Fr., *Coniophora cerebella* Pers., *Polystictus versicolor* (L.) Fr., *Isaria* sp., *Polyporus lucidus* (Leys.) Fr., *Polystictus hirsutus* Fr., *Aspergillus glaucus*,[2] *A. niger* Van Tieg., *A. fumigatus* Brizi, *A. versicolor* Tiraboschi, and *A. Sydowi* Bainier and Sartory.

All the fungi were grown upon 2 per cent potato agar plates prepared in the manner previously described.[3] After growth

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[1] Harder, R. Uber das Verhalten von Basidiomyceten und Ascomyceten in Mischkulturen. Naturwiss. Zeitschr. f. Forst- u. Landw. 9: 129–160. *pl. 3–4. f. 1–2.* 1911.

[2] Thanks are due to Dr. Charles Thom for the determination of the *Fungi Imperfecti* included in this list.

[3] Zeller, S. M., Schmitz, H., and Duggar, B. M. Studies in the physiology of the fungi. VII. Growth of wood-destroying fungi on liquid media. Ann. Mo. Bot. Gard. 6: 137–142. 1919.

TABLE I

Fungus	Organisms stimulating	Organisms inhibiting	Organisms overgrowing	Organisms not influencing
L. vialis	D. quercina*	T. Peckii*, P. sapidus*, Isaria*, A. niger†, A. Sydowi*	T. Peckii, P. versicolor, P. hirsutus	L. vialis, L. lepideus, D. confragosa
M. pinastri		D. quercina†, T. Peckii*, L. lepideus*, D. confragosa†, C. cerebella†, P. versicolor*, P. lucidus*, P. hirsutus*, A. fumigatus†, A. Sydowi*	M. pinastri, T. Peckii, P. sapidus, A. niger	M. pinastri
D. quercina	M. lacrymans*, D. confragosa*, P. lucidus*, P. hirsutus*	M. pinastri†, L. lepideus*, C. cerebella*, Isaria*, A. niger*	T. Peckii, P. sapidus, P. versicolor	L. vialis, D. quercina
T. Peckii	D. quercina*, A. fumigatus*, A. glaucus*	D. confragosa*, Isaria*, A. glaucus*, A. versicolor†, A. Sydowi*	P. sapidus	
P. sapidus		L. vialis*, L. lepideus†, P. versicolor†, P. lucidus*, P. hirsutus†	D. quercina, M. lacrymans	P. sapidus
M. lacrymans		L. lepideus†, P. versicolor†, P. lucidus†, A. fumigatus†	M. pinastri, T. Peckii	
L. lepideus		M. pinastri*, P. sapidus†, P. lucidus†	T. Peckii, P. versicolor	L. vialis
D. confragosa	M. lacrymans†	M. pinastri†, T. Peckii†, P. lucidus†, P. hirsutus†	P. sapidus	L. vialis, A. fumigatus
C. cerebella	L. vialis,* M. lacrymans†	M. pinastri†, D. quercina†, P. versicolor*, A. glaucus*, A. niger*	T. Peckii	

P. versicolor	T. Peckii*	A. versicolor†, A. Sydowi†, M. pinastri*, P. sapidus†, A. niger*, M. lacrymans†, D. confragosa†, C. cerebella†*, P. lucidus†, P. hirsutus†, A. fumigatus*	D. quercina	P. versicolor, A. glaucus
Isaria sp.?		M. pinastri†, A. niger†	P. sapidus, P. versicolor, P. lucidus, P. hirsutus	Isaria
P. lucidus	M. lacrymans*, Isaria*, A. niger*	L. vialis†, M. pinastri*, P. sapidus*, M. lacrymans†, L. lepideus†, D. confragosa†, C. cerebella*, P. versicolor†, A. glaucus†, A. versicolor†	T. Peckii, A. niger	P. lucidus
P. hirsutus		M. pinastri*, P. sapidus†, D. confragosa†, P. versicolor†, A. versicolor*, A. Sydowi*, A. glaucus*	L. vialis, T. Peckii, M. lacrymans, B. cerebella, P. lucidus	P. hirsutus
A. glaucus		T. Peckii*, C. cerebella*, P. hirsutus*, A. glaucus†, A. niger†, A. fumigatus*, A. versicolor†	L. vialis, T. Peckii, P. sapidus, P. lucidus, P. hirsutus	A. fumigatus, A. Sydowi
A. niger		A. versicolor*, A. Sydowi†, D. quercina*, M. lacrymans†, D. confragosa*, C. cerebella*, P. lucidus*, P. hirsutus*, A. glaucus†, A. fumigatus*	T. Peckii, P. sapidus	
A. fumigatus		M. pinastri†, M. lacrymans†, A. glaucus*, A. versicolor†, A. Sydowi†	T. Peckii, Isaria, P. lucidus	D. confragosa, A. fumigatus
A. versicolor		P. hirsutus*, A. fumigatus†, A. glaucus†	P. sapidus, A. Sydowi	P. versicolor, A. glaucus
A. Sydowi		P. hirsutus*, A. niger†, A. fumigatus†	P. sapidus, Isaria, P. lucidus, A. versicolor	

*=after contact; † =before contact.

of the fungi the plates were cut into small squares (about 8 mm. square), which were used as inocula. Agar plates made in a similar manner were each inoculated with three of the fungi in such a way as to have all possible combinations of each fungus. From these plates the reciprocal influence of growth was determined. The results of the plate cultures are shown in table I.

The outstanding feature of these results is the preponderance of inhibition of growth of one fungus before and after contact with another. In some cases this inhibition took place when the two colonies were still a considerable distance apart; in others only when they came into close proximity with each other. Figures 5 and 2 respectively of pl. 4 illustrate this feature. In those cases where inhibition occurred after contact the condition is shown by a straight line unless one fungus has a much more rapid growth than the other. Figures 8 and 11 illustrate this point. It often happened that one fungus on the plate grew much more rapidly than the other two, cutting off contact between them. Therefore, all possible combinations could not be recorded in the table.

There were not as many instances where one fungous colony grew over another as there were of inhibition of growth. In some cases of the former type one colony was completely covered, and the shape of the submerged colony determined that of the colony of the invading fungus, as, for example, in the case of *Pleurotus sapidus* growing over *Aspergillus glaucus* and *A. Sydowi* (see figs. 3 and 6). In these cases the growth of *Pleurotus sapidus* is greatly accelerated as soon as it reaches the colonies. In other cases the growth of the invading fungus was comparatively slow, as, for example, when *Pleurotus sapidus* invaded a colony of *Aspergillus niger* (see fig. 9). At first both of these fungi were mutually inhibited and then *Pleurotus sapidus* gradually advanced. A peculiarity of this special case is the fact that the spores of *Aspergillus niger* disappeared in the invaded section. It could not be determined whether these spores germinated or were digested.

When two colonies of the same fungus came into contact there was usually no influence of the one colony on the other; that is, the mycelium of the two thoroughly intermixed, as fig. 12 in the plate shows for *Merulius pinastri.* An exception to this general condition is illustrated when two colonies of *Aspergillus niger* grew together. At first there was an inhibition of growth as shown by a straight line formed by the margins of the two colonies. Later, however, the two colonies generally intermixed. As table I shows, there was often an intermixing of the mycelium of two different species. This may be explained by the theory advanced by Clark[1] that many deleterious substances, which at certain concentrations retard growth, later cause great acceleration of mycelial development in the retarded cultures.

Cases of stimulation of growth when two colonies came into contact were comparatively rare, while cases of stimulation before contact occurred seldom indeed. However, examples of both these types were observed. In many cases it is hard to distinguish between true stimulation and a mere heaping up of the mycelium due to mechanical hindrance. Figures 7 and 10 of the plate show a stimulation of *Trametes Peckii* in contact with *Daedalea quercina.* At first there was a heaping up of the mycelium, and this appeared to be a great stimulation of growth. However, this may equally well be considered a mere increase in the amount of aërial mycelium due to a mechanical hindrance of the surface of the medium. A peculiar case of stimulated growth of *Daedalea confragosa* is shown in fig. 1. It is not certain whether this is caused by the presence of *Merulius lacrymans* or some other factor. However, there does not seem to be any valid reason why a stimulation by diffusion should not be expected as much as inhibition of growth by diffusion, as where *Lentinus lepideus* and *Aspergillus glaucus* are mutually inhibited before contact. In the latter case the colonies never came together. A slight stimulation of growth of *Polyporus lucidus* in the neighborhood of *Isaria* is shown in fig. 4.

It was noticed that the sporulation of certain of the *Fungi Imperfecti* was influenced by the growth of other fungi. For example, there seemed to be an increase in size and number of the heads of conidiospores of *Aspergillus Sydowi* when in contact with *Merulius pinastri*, and the same is true of *Aspergillus niger* in contact with *A. glaucus*.

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[1] Clark, J. F. On the toxic effect of deleterious agents on the germination and development of certain filamentous fungi. Bot. Gaz. 28: 289–327, 378–404. 1899.

As previously mentioned, hydrogen ion concentrations of solutions were determined after fungi had grown on them for two weeks, and the results obtained indicate that there is no definite relation between the active acidity produced by these fungi and their ability to inhibit or stimulate the growth of another. For example, in fig. 3, *Pleurotus sapidus* grew over *Aspergillus glaucus* very rapidly, but was entirely inhibited by *A. versicolor* on the solid agar medium. In the solutions *Pleurotus sapidus* produced an active acidity of P_H 5.4, while *Aspergillus glaucus* and *A. versicolor* changed the active acidity to about the degree P_H 6.6 and P_H 6.4, respectively; also, *Trametes Peckii* grew over both *Daedalea quercina* and *Aspergillus fumigatus*, although the change in active acidity produced by *Daedalea quercina* was P_H 3.0 and that produced by *Aspergillus fumigatus* was P_H 6.6. Many such examples could be cited by comparing with table I the following active acidities produced by the fungi: *Lenzites vialis*, P_H 5.0; *Merulius pinastri*, P_H 7.0; *Daedalea quercina*, P_H 3.0; *Trametes Peckii*, P_H 4.2; *Pleurotus sapidus*, P_H 5.4; *Merulius lacrymans*, P_H 5.0; *Lentinus lepideus*, P_H 5.4; *Daedalea confragosa*, P_H 5.8; *Coniophora cerebella*, P_H 5.4; *Polystictus versicolor*, P_H 5.4; *Isaria* sp., P_H 6.8; *Polyporus lucidus*, P_H 5.4; *Polystictus hirsutus*, P_H 5.2; *Aspergillus glaucus*, P_H 6.6; *A. niger*, P_H 5.8; *A. fumigatus*, P_H 6.6; *A. versicolor*, P_H 6.4; and *A. Sydowi*, P_H 6.8. The control solution upon which no fungi had grown had an active acidity of P_H 5.4. Of course, there are some instances where similar effects could be correlated with similar changes in hydrogen ion concentration; for instance, *Trametes Peckii* is similarly influenced by both *Aspergillus fumigatus* and *A. glaucus*.

The fungi were also grown on a nutrient solution containing the same ingredients as the agar previously mentioned. Since certain of the *Basidiomycetes* used do not grow well upon liquid media it was found desirable to add to the cultures sufficient quartz sand, free from all soluble substance, so that a slope of sand could be formed above the surface of the solution out into which the solution diffused. All of the *Basidiomycetes* grew well upon these sand slopes, and the solution was easily drained from the sand at the end of the period of culture. After two weeks' growth of the fungi the hydrogen ion concentration of the solutions was determined according to the methods previously cited.[1]

In cases where there was a marked stimulation or inhibition of growth between two fungi on the plates, these fungi were then grown on similar sand slopes. After they had made considerable growth the solution was filtered off, sterilized, and prepared for inoculation with the reciprocal fungus. Controls of these solutions were kept uninoculated. The amount of growth of the second inoculation was determined by the dry weight of the fungous mat and the amount of sugar remaining in the solutions estimated. The latter was accomplished by reducing equal amounts of the solutions with equal amounts of Fehling's solution and estimating visually the amounts of copper oxide. The distinctions were so evident that quantitative determinations were unnecessary.

The dry weight of mycelium produced in each case and an estimation of the amount of sugar remaining in the solution after growth of the first and second fungus are shown in table II.

In some cases it would seem that the carbohydrate content of the nutrient solution upon which a fungus had previously grown might have been the limiting factor for growth. In others, however, this is not true; for example, when *L. vialis* follows *A. niger* there is very little growth, although the carbohydrate content was high, while in the control solution upon which no fungus had grown *L. vialis* made considerable growth and used a greater part of the sugar in the solution. This would tend to indicate that *A. niger* in its metabolism may have secreted some substance which was toxic to the growth of *L. vialis*. It is of course quite probable that such toxic substances were formed in many more instances but were destroyed in the process of autoclaving between the first and second inoculation.

This in general agrees with the conclusions reached by Fulton[2] that fungi in their growth show a more marked tendency to grow

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[1] Zeller, Schmitz, and Duggar, *l. c.*

[2] Fulton, H. R. Chemotropism of fungi. Bot. Gaz. 41:81–108. 1906.

TABLE II

RELATION OF THE AMOUNT OF GROWTH TO THE QUANTITY OF SUGAR REMAINING IN THE SOLUTION

Fungus	Grown on solution after	Dry weight of mycelium (gms.)	Relative amounts of remaining sugars
L. vialis	A. niger	.080	Much
	A. Sydowi	.062	Trace
	Control	.221	Medium
M. pinastri	T. Peckii	.115	Trace
	A. niger	.040	Trace
	Control	.119	None
T. Peckii	M. lacrymans	.154	Much
	P. sapidus	.335	Much
	Isaria	.140	Medium
	A. niger	.084	Trace
	A. fumigatus	.118	Medium
	A. glaucus	.126	Medium
	Control	.221	Much
P. sapidus	A. niger	.302	None
	A. glaucus	.180	Trace
	A. Sydowi	.309	Trace
	Control	.353	Much
M. lacrymans	T. Peckii	.178	Trace
	D. confragosa	.100	Trace
	Control	.230	Much
L. lepideus	T. Peckii	.094	Medium
	A. niger	.073	Trace
	A. fumigatus	.100	Trace
	Control	.111	Much
D. confragosa	M. lacrymans	.290	Trace
	Control	.231	Much
P. versicolor	P. sapidus	.372	Trace
	A. glaucus	.085	None
	A. Sydowi	.088	Trace
	Control	.266	None
P. lucidus	Isaria	.117	Trace
A. niger	P. sapidus	.270	Medium
	M. lacrymans	.240	Trace
	D. confragosa	.141	Trace
	C. cerebella	.270	Trace
	A. fumigatus	.078	None
	Control	.270	Trace
A. fumigatus	C. cerebella	.156	Much
	Control	.158	Trace

out and *away from* the medium influenced by their own growth metabolism than to grow *towards* a diffusion center, whether this center contains nutritive or deleterious materials. This may also be the condition produced in stale cultures.

Thanks are due to the Missouri Botanical Garden for the facilities of the library and the laboratories and to Dr. B. M. Duggar for helpful co-operation.

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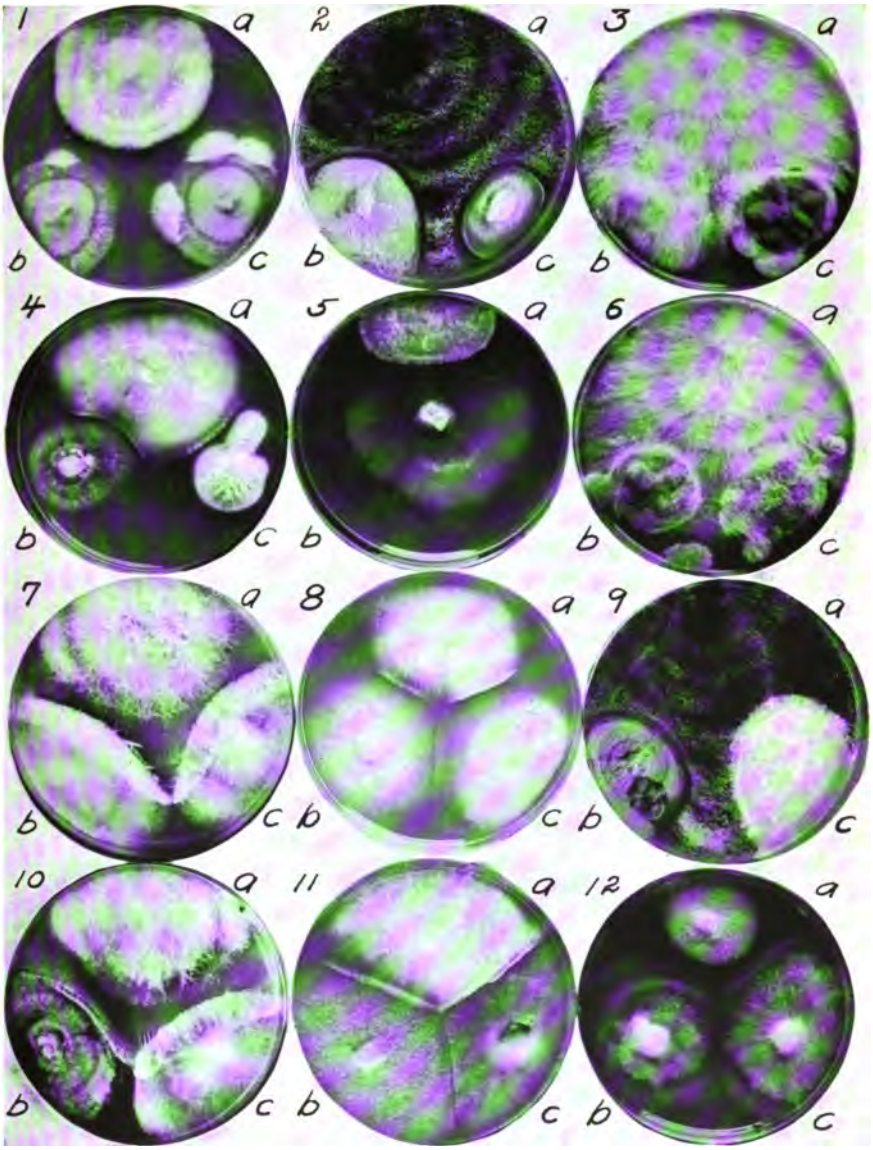
EXPLANATION OF PLATE

PLATE 4

Fig. 1. *a*, *Merulius lacrymans;* *b* and *c*, *Daedalea confragosa.*
Fig. 2. *a*, *Aspergillus niger;* *b*, *A. fumigatus;* *c*, *Lentinus lepideus.*
Fig. 3. *a*, *Pleurotus sapidus;* *b*, *Aspergillus glaucus;* *c*, *A. versicolor.*
Fig. 4. *a*, *Polyporus lucidus;* *b*, *Lenzites vialis;* *c*, *Isaria* sp.
Fig. 5. *a*, *Aspergillus fumigatus;* *b*, *Lentinus lepideus.*
Fig. 6. *a*, *Pleurotus sapidus;* *b*, *Aspergillus Sydowi;* *c*, *A. glaucus.*
Fig. 7. *a*, *Trametes Peckii;* *b* and *c*, *Daedalea quercina.*
Fig. 8. *a*, *Polyporus lucidus;* *b*, *Polystictus hirsutus;* *c*, *Trametes Peckii.*
Fig. 9. *a*, *Aspergillus niger;* *b*, *A. fumigatus;* *c*, *Pleurotus sapidus.*
Fig. 10. *a*, *Trametes Peckii;* *b*, *Lenzites vialis;* *c*, *Daedalea quercina.*
Fig. 11. *a*, *Polyporus lucidus;* *b*, *Polystictus hirsutus;* *c*, *Merulius pinastri.*
Fig. 12. *a*, *Daedalea quercina;* *b* and *c*, *Merulius pinastri.*



ZELLER AND SCHMITZ—MIXED CULTURES

15

STUDIES IN THE PHYSIOLOGY OF THE FUNGI

IX. ENZYME ACTION IN ARMILLARIA MELLEA VAHL, DAEDALEA CONFRAGOSA (BOLT.) FR., AND POLYPORUS LUCIDUS (LEYS.) FR.

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Careful studies in the physiology of the wood-destroying fungi have but recently received the degree of consideration to which their economic importance entitles them. Many economic forms are as yet untouched, and it is our purpose to study some of the fundamental physiological relations existing between fungus and host. The following is the first of a series of investigations concerning especially the enzyme activities of such forms. It is recognized that *Armillaria mellea* has received considerable attention in respect to its physiological relations because of its importance as a root rot of fruit trees, but, as far as the writers are aware, there has been no physiological study of *Daedalea confragosa* or *Polyporus lucidus*, both of which must be recognized as important wood-rotting fungi.

In a recent paper by one of us[1] the literature and methods of enzyme study in the wood-destroying fungi have been sufficiently reviewed, so that in the present paper only specific references to previous literature will be made, and unless otherwise stated, the methods followed will be those previously described.

The fungi from which was obtained the fungous meal used in the present study were grown on sterile, sliced carrot in large Erlenmeyer flasks. While still in an active growing condition the fungous mats were removed and rapidly air-dried by means of an electric fan. When thoroughly dry the material was finely ground.

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[1] Zeller, S. M. Studies in the physiology of the fungi. II. Lenzites saepiaria Fries, with special reference to enzyme activity. Ann. Mo. Bot. Gard. 3: 439–512. *pl. 8–9.* 1916.

ESTERASES

In the study of the esterases of these three fungi methyl acetate, ethyl acetate, ethyl butyrate, triacetin, and olive oil emulsion were used as substrates. When esterases act upon esters fatty acids are liberated, and thus the concentration of the active acidity can be used as an index of the degree of enzyme action. First, a determination was made of the hydrogen ion concentration of the substrate. A similar determination was also made of the substrate to which a certain amount of autoclaved fungous meal had been added. These two determinations did not always check, due to the introduction of certain substances with the fungous meal and perhaps also to certain buffer effects. The latter determination was taken as the control in each case and compared with a third determination made of the substrate to which a similar amount of fungous meal had been added and incubated twenty-one days.

It was found that there was no apparent esterase activity of any of the fungi on any of the substrates except methyl acetate upon which a slight esterase activity was shown in the case of *Daedalea confragosa* and *Polyporus lucidus*. These results are similar to those found for *Lenzites saepiaria*.[1]

CARBOHYDRASES

The action of carbohydrases was determined upon maltose, lactose, sucrose, raffinose, potato starch, inulin, cellulose from various sources, and hemicellulose. The amount of sugars which reduce Fehling's solution in the enzyme cultures after incubation was taken as the index of enzyme activity. Since this study is merely to indicate the relative activity between the different fungi on the different substrates the results are given as the number of cc. of N/20 potassium permanganate required to oxidize the dissolved copper oxide. The results in the following table are the averages of duplicate enzyme cultures after the Fehling's control had been deducted.

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[1] Zeller, S. M., *l. c.*

TABLE I

SHOWING THE ACTION OF CARBOHYDRASES ON POLYPORUS LUCIDUS, ARMILLARIA MELLEA, AND DAEDALEA CONFRAGOSA

Incubation period	Substrate	P. lucidus			A. mellea		D. confragosa	
		With fungous meal	With fungous meal autoclaved	Without fungous meal	With fungous meal	With fungous meal autoclaved	With fungous meal	With fungous meal autoclaved
		Number of cc. of $\frac{N}{20}$ KMnO$_4$						
14 days	Maltose	36.1	16.3	13.1	36.2	16.3	23.5	14.7
24 days	Lactose	31.7	23.0	18.8	36.9	26.0	24.9	19.3
6 hours	Sucrose	27.5	1.6	1.0	31.3	2.3	11.1	0.3
2 days	Raffinose	32.5	5.2	0.8	12.5	2.6	12.5	0.6
6 hours	Potato starch	19.2	6.1	1.4	25.3	2.6	7.7	1.5
2 days	Inulin	20.3	4.9	0.8	15.4	2.4	7.8	0.9
28 days	Ash cellulose	5.6	0.7	0.3	4.1	0.5	4.3	1.8
28 days	Fir cellulose	5.8	0.3	0.2	3.3	0.4	4.7	0.4
28 days	Oak cellulose	3.8	0.2	0.1	3.6	0.1	3.1	1.3
28 days	Hemicellulose	4.4	0.3	0.1	2.9	0.1	3.2	1.8

In general the carbohydrate activity is greater in *Polyporus lucidus* and *Armillaria mellea* than in *Daedalea confragosa,* with the possible exception of raffinase where the activity in *Daedalea confragosa* approximates that of *Armillaria mellea.* The striking feature of the results is the evident presence of lactase in the three fungi. This is the first record of the presence of lactase in the higher fungi.

In the study of cellulase pure cellulose was prepared from Douglas fir, ash, and red oak, according to the method frequently reported from this laboratory. Suspensions of these in doubly distilled water were used as substrates. After the enzyme culture had been incubated for 28 days there was a marked increase in the amounts of reducing sugars produced by all the fungi on all of the substrates.

For a hemicellulose substrate cleaned autoclaved endosperms from date seeds were used. These were shaved into very thin slices and placed in distilled water with the fungous meal. Hydrolysis quite comparable to that produced in the cellulose experiments resulted in each case as is indicated in table I.

EMULSIN

The presence or absence of emulsin was determined by the effect of the fungous meal upon amygdalin, which upon hydrolysis produces glucose, benzaldehyde, and hydrocyanic acid. After incubation of seven days the amount of glucose present in the cultures was determined as in the cases where carbohydrates were used as substrates, and the results are tabulated in the following table:

TABLE II

SHOWING THE ACTION OF EMULSIN ON POLYPORUS LUCIDUS, ARMILLARIA MELLEA, AND DAEDALEA CONFRAGOSA

Enzyme culture	P. lucidus	A. mellea	D. confragosa
	Number of cc. of $\frac{N}{20}$ $KMnO_4$		
1% amygdalin+ fungous meal	26.0	12.5	18.1
1% amygdalin+ fungous meal (autoclaved)	4.8	0.6	0.1
1% amygdalin	0.6	0.6	0.6

In all cases where the above sugar tests showed evidence of the breaking down of amygdalin the odor of benzaldehyde was easily recognized. There was evidence of emulsin in all three of the fungi used.

TANNASE

In order to determine the tannase activity the gallic acid, which is a product of hydrolysis of tannic acid, was titrated with standard iodine solution. The results show the presence of tannase in *Polyporus lucidus* and *Daedalea confragosa* but none was detected in *Armillaria mellea.* This fact seems peculiar, since the rhizomorphs of *Armillaria mellea* are usually found next to the inner bark of the woody tissues where the tannin is usually present in the greatest amount for the specific host. The fact that the fungi from which the fungous meal was made were grown on carrot may have had some influence on the production of tannase in this particular instance.

AMIDASE AND UREASE

The presence of the enzymes which split amino acids and urea into ammonia and hydroxy acids was demonstrated by using such substrates as asparagin, acetamid, and urea. The usual Folin method of determining the presence of ammonia is such a time-consuming procedure that a new method was devised involving the indicator method of determining the hydrogen ion concentration of solutions. In brief, the method employed is as follows:

The substrate and fungous meal in the desired proportions were placed in wash bottles, the inlets and outlets of which were sealed with rubber tubes and clamps in order to retain any ammonia which might have been given off during the period of incubation. After a period of incubation of seven days the ammonia was drawn directly through another small wash bottle by means of a Richards pump. The small wash bottle contained 10 cc. of doubly distilled water to which was added 6 drops of brom thymol blue made up in the proportions suggested by Clark and Lubs.[1] This doubly distilled water had a hydrogen ion concentration of P_H 5.6, at which concentration the indicator was yellowish brown. Due to the hydrogen ion concentration decreasing as the ammonia is drawn through, the color changes from green to blue. The length of time taken to change from P_H 5.6 to P_H 7.0 would, of course, depend upon the amount of ammonia present, and this was thus taken as a criterion of the relative rate of ammonia production in the various enzyme cultures. In no case was the gas drawn through the wash bottle for a period longer than three minutes. At the end of this period the actual hydrogen ion concentration of the distilled water was determined. Sometimes the change was so rapid that it was not necessary to run the experiment for three minutes. In such instances other indicators having a wider alkaline range were substituted for brom thymol blue. In the urea control there was a change from P_H 5.6 to P_H 6.0, and thus, for urea, changes not going beyond P_H 6.0 were considered as negative. The results are tabulated in table III.

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[1] Clark, W. M., and Lubs, H. A. The colorimetric determination of hydrogen ion concentration and its applications in bacteriology. Jour. Bact. 2: 1–34, 109–136, 191, 236. 1917.

Urease was demonstrated for the three fungi. It was most pronounced in *Daedalea confragosa* and least in *Polyporus lucidus*. Only *Armillaria mellea* showed slight amidase action when acetamid was used as a substrate. There was no amidase action when asparagin was used as a substrate.

Due to the fact that traces of alkalis or acids cause considerable shifting of the hydrogen ion concentration in such an unbuffered solution as doubly distilled water it is believed that this method can be used to determine the presence of minute traces of ammonia which would be undetectable by the methods usually employed, and the determination is much more rapid. In the present paper only relative determinations were necessary but there is no valid reason why quantitative determinations could not be made by this method.

PROTEASES

Tryptic and ereptic fermentation was studied by the use of albumin, peptone, casein, legumin, and fibrin in enzyme cultures having a neutral, acid, and alkaline reaction. When fibrin was used as a substrate positive results were obtained to show the presence of both trypsin and erepsin in all three of the fungi. These results were most pronounced in the cultures having an acid reaction and least in those with an alkaline reaction. In the case of the plant protein, legumin, there was very slight indication of the presence of tryptic and ereptic fermentation only in *Polyporus lucidus* and only when the substrate was acid in reaction. In *Polyporus lucidus* there was indication of the presence of trypsin when albumin of acid reaction was used. This was not true of *Armillaria mellea* or *Daedalea confragosa.* In no case was there a splitting of peptone or casein.

TABLE III

UREASE AND AMIDASE ACTIVITY IN ARMILLARIA MELLEA, DAEDALEA CONFRAGOSA, AND POLYPORUS LUCIDUS

	Enzyme culture	No.	Change in H ion concentration. P_H values		
			Urea	Acetamid	Asparagin
P. lucidus	Substrate + fungous meal	1	5.6–6.8 3 min.	5.6–5.6 3 min.	5.6–5.6 3 min.
		2	5.6–6.6 3 min.	5.6–5.6 3 min.	5.6–5.6 3 min.
	Substrate + fungous meal (autoclaved)	3	5.6–6.0 3 min.	5.6–5.6 3 min.	5.6–5.6 3 min.
		4	5.6–5.8 3 min.	5.6–5.6 3 min.	5.6–5.6 3 min.
A. mellea	Substrate + fungous meal	1	5.6–7.2 30 sec.	5.6–6.0 3 min.	5.6–5.6 3 min.
		2	5.6–7.2 25 sec.	5.6–6.0 3 min.	5.6–5.6 3 min.
	Substrate + fungous meal (autoclaved)	3	5.6–6.0 3 min.	5.6–5.6 3 min.	5.6–5.6 3 min.
		4	5.6–6.0 3 min.	5.6–5.6 3 min.	5.6–5.6 3 min.
D. confragosa	Substrate + fungous meal	1	5.6–7.2 1 sec.	5.6–5.6 3 min.	5.6–5.6 3 min.
		2	5.6–8.8 3 sec.	5.6–5.6 3 min.	5.6–5.6 3 min.
	Substrate + fungous meal (autoclaved)	3	5.6–6.0 3 min.	5.6–5.6 3 min.	5.6–5.6 3 min.
		4	5.6–6.0 3 min.	5.6–5.6 3 min.	5.6–5.6 3 min.
Control	Substrate alone	1	5.6–6.0 3 min.	5.6–5.6 3 min.	5.6–5.6 3 min.
		2	5.6–6.0 3 min.	5.6–5.6 3 min.	5.6–5.6 3 min.

Summary

In *Polyporus lucidus* the presence of the following enzymes is demonstrated: esterase, maltase, lactase, sucrase, raffinase, diastase, inulase, cellulase, hemicellulase, emulsin, tannase, urease, and trypsin and erepsin when fibrin is used as a substrate.

In *Armillaria mellea* the presence of the following enzymes is demonstrated: maltase, lactase, sucrase, raffinase, diastase, inulase, cellulase, hemicellulase, emulsin, urease, amidase, and trypsin and erepsin when fibrin is used as a substrate.

In *Daedalea confragosa* the following enzymes are present: esterase, maltase, lactase, sucrase, raffinase, diastase, inulase, cellulase, hemicellulase, emulsin, tannase, urease, and trypsin and erepsin when fibrin is used as a substrate.

A new method for the determination of ammonia liberated by amidase is described. This method involves the application of the indicator method for hydrogen ion concentration determination.

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Graduate Laboratory, Missouri Botanical Garden.

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